

A CONTROL SYSTEM FOR A STANDARD
DEVICE FOR CALIBRATING CALORIMETER ROOMS

by

WILLIAM EMANUEL KRAMER

B.S., Kansas State University, 1982

A THESIS

submitted in partial fulfillment of

the requirements for the degree

MASTER OF SCIENCE

Department of Mechanical Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1984

Approved by:


Major Professor

PREFACE

This thesis describes the design and testing of the control system for a research project entitled "A Standard Device for Calibrating Calorimeter Rooms". Chapter one, of this thesis, describes the systems to be controlled and chapter two highlights the control strategy. Chapter three is a description of the simulation of the control system and chapter four describes the testing of the control system. Chapter five discusses the conclusions and recommendations for further study. The appendices include detailed descriptions of both the hardware and the software required to implement the control system.

I would like to extend my thanks to all the faculty members who made contributions to this research. I would especially like to commend Dr. J. Garth Thompson for his excellence both as a teacher and as an engineer. Dr. Thompson's guidance and suggestions have helped me to grow both as an engineer and as an individual. I would also like to thank Dr. Terry Beck and Dr. Byron Jones for their guidance and suggestions.

I want to thank Earl Campbell for his ideas and help in developing the software and hardware for this project and I would like to thank Mark Thowe, who will continue with this research, for both his time and his contributions.

And finally a special thanks to my wife, Lestel, who has been a support to me throughout my graduate curriculum.

TABLE OF CONTENTS

| | |
|---|----|
| Chapter | |
| I. INTRODUCTION..... | 1 |
| II. CONTROL STRATEGY..... | 9 |
| Block Diagram Description..... | 9 |
| III. COMPUTER SIMULATION OF THE CONTROL STRATEGY..... | 16 |
| IV. TESTING THE CONTROL SYSTEM..... | 26 |
| Step Input..... | 28 |
| System Startup..... | 30 |
| Thermal Noise..... | 30 |
| Cold Start..... | 34 |
| Zero Offset Test..... | 39 |
| Steady State Analysis..... | 40 |
| Response to a Change in Power to Calib. Heater..... | 43 |
| V. CONCLUSIONS AND RECOMMENDATIONS..... | 46 |
| LIST OF REFERENCES..... | 48 |
| APPENDIX A HARDWARE..... | 50 |
| The Motor Driven Variac..... | 50 |
| The Motor Driven Rheostat..... | 51 |
| The Controllability of the Rheostat and Variac..... | 55 |
| The Flow Control Valves..... | 56 |
| Analog to Digital Converter and Pin Connections.... | 62 |
| APPENDIX B NONLINEAR FUNCTION FLOWCHART..... | 65 |
| APPENDIX C PROGRAM LISTINGS..... | 68 |
| Program Simash | 69 |
| Program ASHRAE 14 | 72 |
| Program ASHRAE 14 Demo..... | 80 |
| Program Plot V.1.BAS..... | 83 |
| Program Mean bas..... | 85 |

LIST OF TABLES

| | | |
|---------|---|----|
| Table 1 | Component Summary for Figure 1.1..... | 3 |
| Table 2 | Stepping Motor Stepping Sequence..... | 51 |
| Table 3 | Port A Section 2 of Base Board Bit Pattern for Flow Valve Control..... | 62 |
| Table 4 | Analog Input Board Connections..... | 63 |
| Table 5 | Lab Master I/O Interface Board Connections..... | 64 |

LIST OF FIGURES

Figure

| | | |
|------|--|----|
| 1.1 | Proposed System Design..... | 2 |
| 1.2 | Experimental Test System..... | 5 |
| 2.1 | Control System Block Diagram..... | 9 |
| 2.2 | Control Heater Power Circuit..... | 11 |
| 3.1 | Step Response *..... | |
| 3.2 | Simulated Response, for $T_h = 0$ | 19 |
| 3.3 | Simulated Response, for $T_h = 0$ (expanded view)..... | 20 |
| 3.4 | Simulated Response, for $T_h = 9$ degrees..... | 21 |
| 3.5 | Simulated Response, $T_h = 9$ degrees (expanded view).... | 22 |
| 4.1 | Step Response *..... | 26 |
| 4.2 | Startup Response *..... | 28 |
| 4.3 | Determination of Noise *..... | 30 |
| 4.4 | Cold Start *..... | 31 |
| 4.5 | System Drifting with no Control (expanded view of 4.4) *..... | 32 |
| 4.6 | Restart Response (expanded view of 4.4) *..... | 34 |
| 4.7 | Restart Response * *..... | 35 |
| 4.8 | Steady State Response *..... | 37 |
| 4.9 | Steady State Response * *..... | 38 |
| 4.10 | Response to a Change in T_{sys} *..... | 40 |
| 4.11 | Response to a Change in T_{sys} * *..... | 41 |
| 5.1 | Stepping Motor Drive Circuitry (variac)..... | 47 |
| 5.2 | Stepping Motor Drive Circuitry (rheostat)..... | 48 |
| 5.3 | Opto Isolation Layout, Base Board..... | 51 |
| 5.4 | Valve 1 Solid State Switching Circuitry..... | 52 |
| 5.5 | Valve 2 Solid State Switching Circuitry..... | 53 |
| 5.6 | Valve 3 Solid State Switching Circuitry..... | 54 |

* Digital Oscilloscope Data

** Computer data 10 samples/sec/data point

CHAPTER I

INTRODUCTION

The purpose of this research project is to develop a control and measurement system for a "A Standard Device for Calibrating Calorimeter Test Rooms." The objective of the research project is to develop an accurate calibration system, which can be duplicated by individual room air conditioner manufacturers, for calibrating calorimeter test rooms. This device will be capable of providing "A Standard Cooling Capacity" that can be measured accurately enough at the manufacturer's location to be considered a secondary standard.

The purpose of the control/measurement system is to make the necessary adjustments in operating conditions, internal and external to the calorimeter room, and to maintain a desired cooling capacity. The control/measurement subsystem will continuously monitor the appropriate temperature, and flow conditions required to accurately determine the total and latent heat loads. It will also perform the necessary calculations "on line" and display all relevant data on the CRT in engineering units for the operator.

Figure 1.1 is a diagram of the overall proposed system (see reference 1). The fluid schematic includes two independent designs. The first approach is based on measuring the flow rate and enthalpy change of a fluid as it passes through a heat exchanger in the calorimeter room. This design is referred to as the indirect measurement method. The second approach

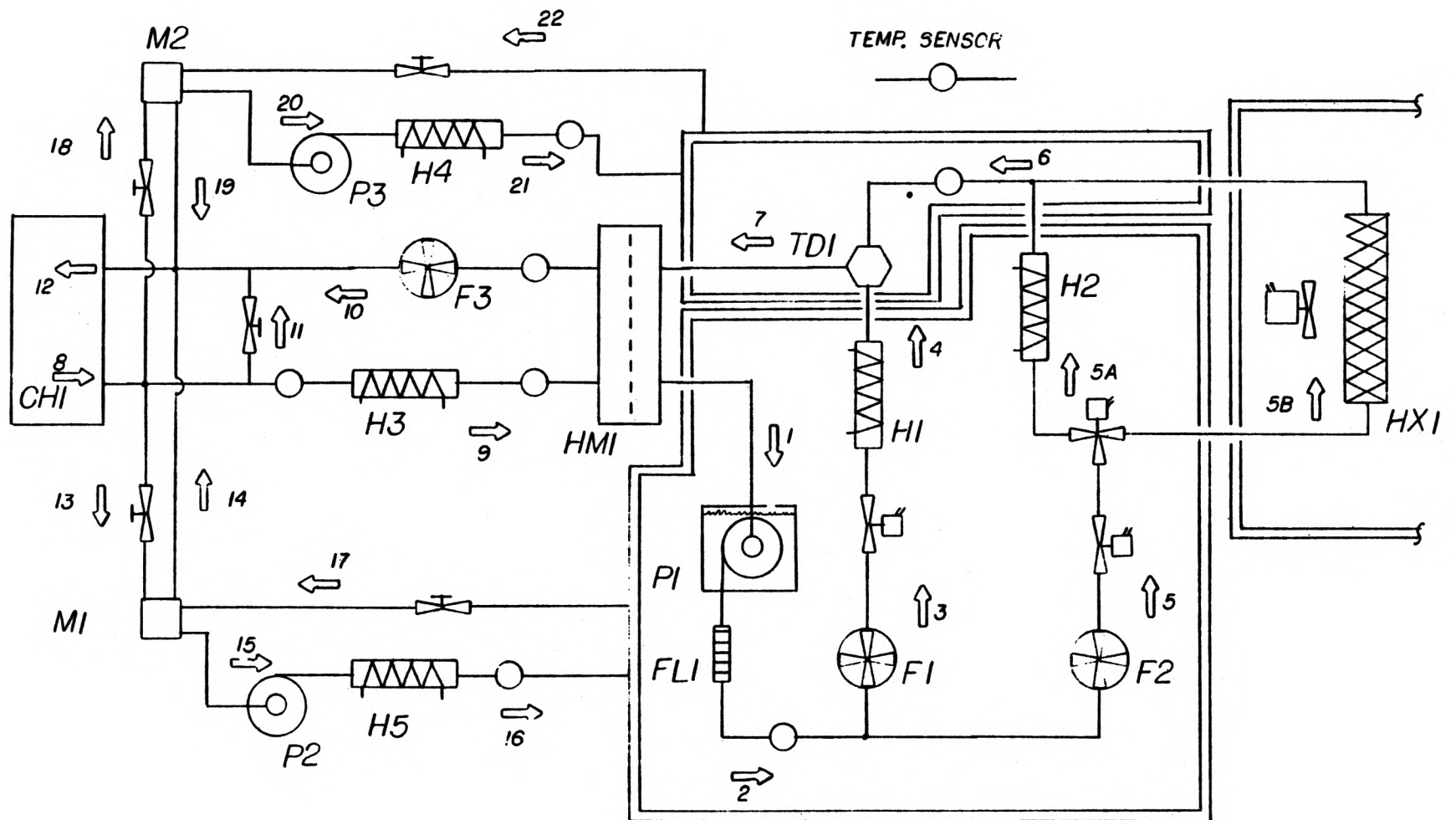


Figure 1.1
Proposed System Design

Table 1. Component Summary

CH1 (chiller) - Thermal Care Model TC1W10

F1 (flowmeter) - Max 214-300 with 284-510 transmitter

F2 (flowmeter) - unspecified --- 5% accuracy ok

FL1 (in-line filter)

H1 (electric heater) - custom built, based on 1000 W high watt submerged cartridge heater

H2 (electric heaters) - same as above but based on two cartridges

H3-H5 (electric heaters) - custom built, based on standard electric water heating elements

HM1 (heat flow meter)

HX1 (water-to-air heat exchanger) - exchanger unspecified, F.W. Bell PX 200 power monitor on fan

M1-M2 (mixing tanks) - custom built

P1 (pump) - 1/2 hp submersible, F.W. Bell PX 2000 power monitor (tentative)

P2-P3 (pumps) - 1/10 hp - unspecified

TD1 (temperature difference sensor) - custom built, based on Melcor CP1.4-127 thermoelectric module

PM1 (power monitor) - Scientific Columbus DL 6070 watt/watt-hr transducer

PM2 (power monitor) - Scientific Columbus DL 6070 watt/watt-hr transducer with special order 50:5 current transformer

R1 (variable resistor) - Ohmite 1.5 ohm rheostat

VT1 (variable transformer) - Staco series 1010 auto-transformer with dc servo drive (may use stepper drive)

VT2 (variable transformer)

uses a heat meter using HM1. The heat meter design (references 12,13,14,15,16) is not used in the research for this thesis and therefore is not discussed. Another part of the proposed system includes the fluid circuits for thermal guarding. The guard boundaries are indicated by double lines in Figure 1.1. The direct measurement approach is shown in the left guard circuit. The flow stream from the pump, P1, is divided so that part of the flow passes through a control heater, H1, outside of the calorimeter room and the rest passes through the heat exchanger, HX1. The heat exchanger cools the chamber. The objective is to accurately measure the heat removed from the chamber by this heat exchanger. The two flow streams come back together in a device which senses the temperature difference between the two streams. The power input to the heater is controlled to keep this average temperature difference as close to zero as possible.

This thesis concentrates on the control strategy required to keep the average temperature difference between two liquid flow streams to be as close to zero as possible. The goals of the research were to :

- 1) Configure a computer system to be used for the control and data acquisition for the research project.
- 2) Develop a control algorithm to maintain the temperature difference sensor within the required tolerances.
- 3) Write a computer simulation program which models the performance of the control and determine the gain values for smooth, stable control.
- 4) Write a computer program which implements the control strategy.
- 5) Test and evaluate the control system using components which will be similar to the research proposal's final design for a given setpoint.

In order to verify the control system for the indirect measurement scheme, an experimental test system was developed from the proposed final design. Figure 1.2 shows all of the necessary components which were required for verifying the control strategy. A calibration heater, H2, is used in place of the heat exchanger to verify the system's operation. The calibration heater is used to simulate a load on the calorimeter room. The operation of the control algorithm as well as the system components can be verified using this test arrangement.

The chiller shown in Figure 1.2 produces a chilled glycol solution which passes through an isolation heat exchanger (bucket) and then returns to the chiller where it is re-cooled. The purpose of the isolation heat exchanger is to isolate the working fluid in the chiller from the fluid in the experimental test system. The test system is a closed fluid system so there will be no need to replenish the system's fluids during a test. A glycol solution leaves the isolation heat exchanger at a temperature which can be adjusted at the chiller through hot gas bypass control. This temperature regulation should be within ± 1 degree Fahrenheit for any set point. The solution then passes through a filter which is used to remove any impurities in the system which could damage any of the sensing equipment used in the system. After the filter, the flow stream is divided into two separate flow paths.

In each path the liquid flows through a flowmeter which gives a series of pulses at a rate which is proportional to the volumetric flow of fluid flowing through it. The flows pass through motor actuated ball valves. The flow rates are controlled by positioning the ball valves using the flow meters as the feedback signal. Flow rates are adjusted to the

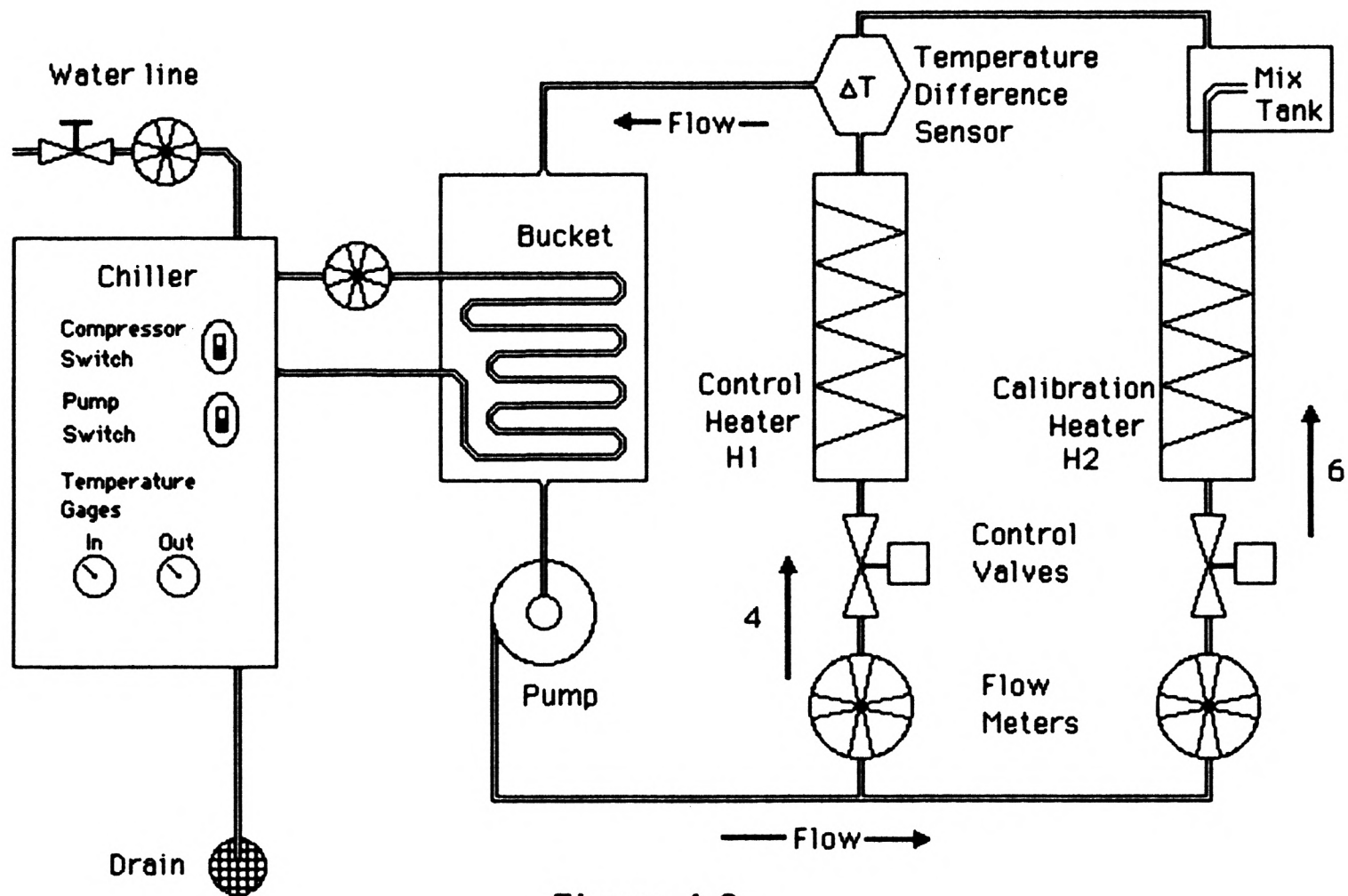


Figure 1.2
Experimental Test System

required test setpoint, and then the flow rates in both paths are not adjusted during a test run.

The liquid in both paths continues from the control valves to the heaters. The power to the control heater can be controlled through the use of a stepper motor driven variac and a stepper motor driven rheostat. The position of each of the stepper motors can be controlled by the computer.

The power to the calibration heater is manually controlled through the use of a variac. In the final design the calibration heater will be used to calibrate the heat motor and it will have a motor driven variac which will be controlled by the control computer.

The two flow streams pass into a temperature difference sensor which produces an analog voltage signal proportional to the temperature difference in the flow streams. The goal of the control strategy is to maintain this temperature difference to be zero so that the equation:

$$\frac{P_h}{P_c} = \frac{\dot{V}_h}{\dot{V}} \quad (1)$$

where P_c is the power to the calibration heater

P_h is the power to the control heater

\dot{V}_h is the flow rate through the control heater

\dot{V} is the flow rate through the calibration heater

can be applied. The equation above is strictly true only if there are no other losses or gains in the system and if the temperature difference in the returning streams is zero. In the final design the flow streams will be thermally guarded to prevent heat loss or gain. In the test system the temperatures were maintained near ambient to reduce losses. According to the report "A Standard Device for Calibrating Calorimeter Rooms - Accuracy Determination (see reference 1), in order to obtain the required accuracy

for the determination of the cooling load, the average temperature for any given set point must not exceed $\pm .0063$ degrees Fahrenheit during steady state conditions.

A control strategy to main the required temperature difference will be developed in the next chapter. A simulation of the control system is described in Chapter III. Chapter IV describes the testing of the control system and Chapter V discusses the conclusions and recommendations.

CHAPTER II

THE CONTROL STRATEGY

The control strategy for controlling the system described in Chapter 1 is shown in the block diagram of Figure 2.1. The control system is a multi-loop feedback system which implements proportional, integral, derivative, PID, compensation for maintaining the temperature difference at the transducer to be as close to zero as possible.

Block Diagram Description

The signal ΔT_{sys} represents the change in the temperature across the heat exchanger or the calibration heater (see Figure 1.1). The signal ΔT_h represents the change in temperature across the control heater. In the physical system, the two flow streams, pass next to a temperature difference transducer and a voltage output signal, proportional to the temperature difference between the two flow paths, is sampled periodically by an analog to digital converter. The gain, K_7 , represents the constant of proportionality between the temperature difference and the voltage output signal from the transducer. The signal X represents the difference in the temperature between the two flow streams.

The signal X is digitized and passed to a PID controller in which is implemented in the computer. The transfer function of the PID controller is:

$$K_d s + K_p + K_i/s \quad (2)$$

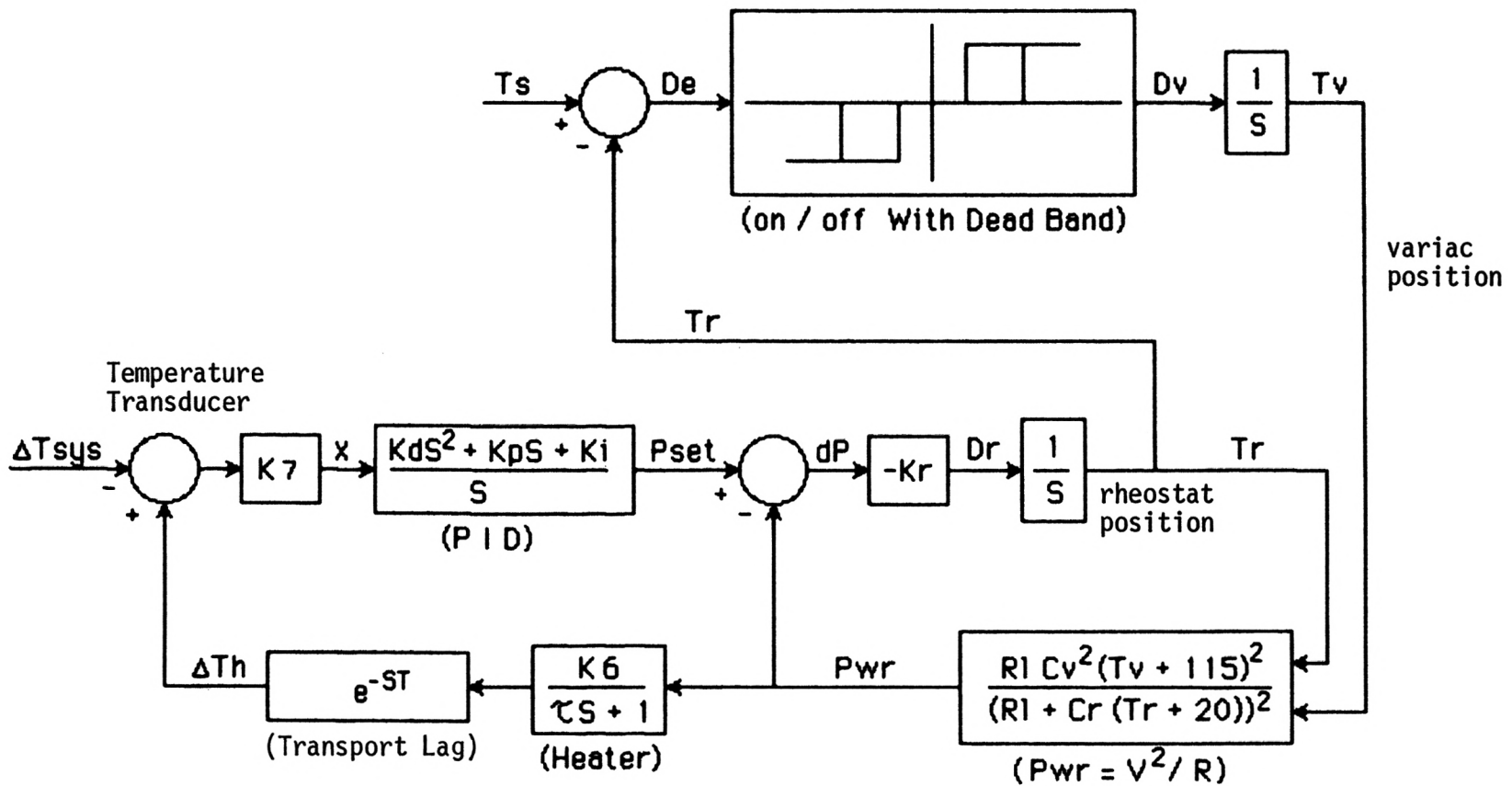


Figure 2.1
Control System Block Diagram

The PID control is widely used for compensation in control systems. The gain K_p represents the proportional gain and controls how fast the system will respond to a given input. K_i is the integral gain and is used to eliminate any steady state errors in the system. K_d is the derivative gain and is a measure of how fast the signal is changing and gives the effect of anticipation.

The output of the PID controller is used as a moving set point for the power control loop. The power to the control heater is measured and used as feedback in this control loop. If the power, P_{wr} , is equal to the P_{set} value, then the resulting change in power, dP , will be zero and no adjustment to the power will be required. When P_{wr} is not equal to P_{set} then the value of dP will be non-zero.

The input to the power control loop is dP which represents the change in power. The amount of change in power will be ultimately controlled by T_r and T_v , the number of windings of the rheostat and variac respectively. In order to properly control the motion of the rheostat and variac it is necessary to take into account the fact that there are limitations to the angular motion for both of these devices. The block diagram of the system must also represent these motion limits. The signal dP is multiplied by a gain $-K_r$ which represents the number of rheostat windings per watt sec. The signal D_r represents the rate of change of the motion of the rheostat. The signal D_r is integrated to obtain the signal T_r which is the absolute angular position of the rheostat. Note that the signal T_r can be either positive or negative in this configuration, where zero windings is halfway between no resistance and full resistance.

The next comparator in the block diagram takes the difference between

a rheostat set point value, T_s and the rheostat position T_r . The difference, D_e , is computed and is an input to a non-linear on/off controller with dead band. This nonlinear controller is used to adjust the variac, course control, when the rheostat exceeds a band around the rheostat set point. A flow chart for implementing this nonlinear control function is given in Appendix B. The output of the on/off control function is the rate of change in angular motion of the variac, D_v . To obtain the position of the variac the rate signal must be integrated. Again, T_v can be either a positive or negative value where 0 windings is halfway between full off and full on.

Both T_v and T_r are inputs into the next block which represents the relationship between the angular position of the variac and rheostat and the power. The power model can be derived using circuit theory and by using the following relationships:

$$\text{resistance of rheostat} = C_r(T_r + 1/2 \text{ max number of windings of rheostat})$$

$$\text{voltage of variac} = C_v(T_v + 1/2 \text{ max number of windings of variac})$$

$$\text{where } C_r = \text{max resistance/max number of windings of rheostat}$$

$$C_v = \text{max line voltage/max number of windings of variac}$$

$$R_l = \text{resistance of the control heater}$$

For the rheostat and variac used, the power is:

$$P_{wr} = R_l C_v^2 (T_v + 115)^2 / (R_l + C_r(T_r + 20))^2 \quad (3)$$

P_{wr} is the power to the control heater and is measured in the physical system using a watt meter transducer which gives a voltage signal proportional to the amount of power. This signal is then converted to watts at the computer where it is compared with P_{set} , which is the output

of the PID transfer function. The purpose of this feedback loop is to provide tight control of the power to the control heater. If there should be a disturbance due to fluctuations in the line voltage then this feedback loop will immediately re-adjust the rheostat and variac to maintain the power level. The amount of power to the control heater is controlled by using a stepper motor driven variac for course control and a stepper motor driven rheostat for fine control. Figure 2.2 is a wiring schematic of the control heater power circuit. The power input to the heater can be controlled either by varying the voltage across the heater or by increasing or decreasing the resistance in series with the heater using the rheostat. In order to control the power to the heater stepping motors are connected to the shafts of the variac and rheostat and direct control of either the input voltage or resistance can be obtained by controlling the positions of the stepping motors.

The next transfer function after the feedback loop is the term:

$$1/(\tau s + 1) \quad (4)$$

This transfer function is the Laplace representation for the thermal lag within the heater. The time constant of the heater, τ , can be obtained by measuring the step response of the heating system. The time constant is defined as being the time that it takes the response from a step input to reach 63 percent of the settling voltage.

The next transfer function of the block diagram is a pure time delay and is of the form:

$$\frac{e^{-sT}}{e} \quad (5)$$

This transfer function is an approximation for the transport lag for the

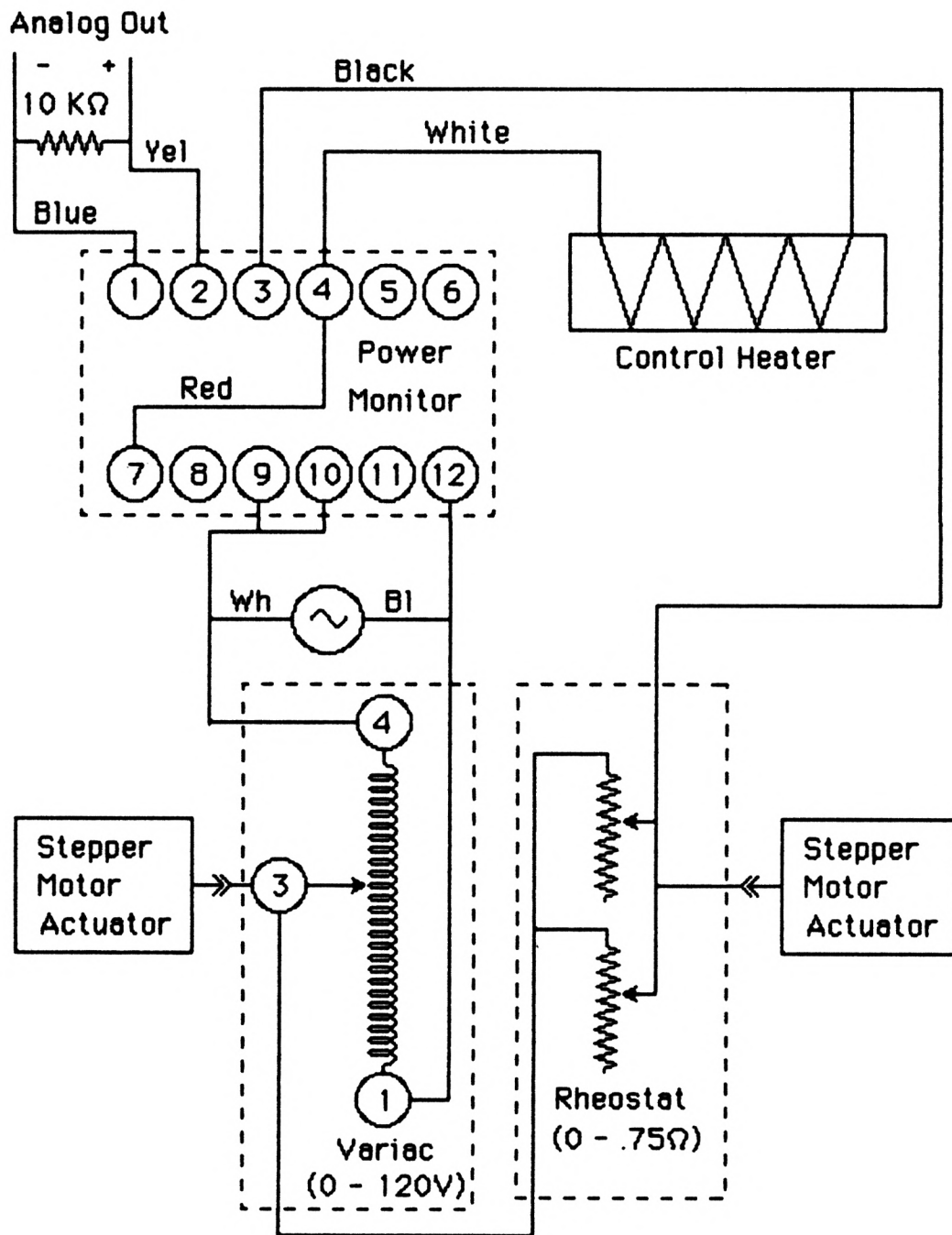


Figure 2.2
Control Heater Power Circuit

flow between the heater and the temperature difference transducer. The time lag and the time constant of the system can be determined, at the same time, by observing the response of the temperature difference transducer when a step input of power is applied to the control heater.

The transfer function, K_6 , is a gain which converts the signal representing the power to a change in temperature. This value of gain is obtained using:

$$q = \dot{m} C_p dT \quad (6)$$

where q = heat transfer

\dot{m} = flow rate

C_p = specific heat of the liquid in the flow stream

dT = temperature difference across the control heater

Solving for dT :

$$dT = \Delta T_h = q / (\dot{m} C_p) \quad (7)$$

The signal ΔT_h is measured in degrees Fahrenheit and will be compared to ΔT_{sys} back at the temperature difference sensor, and the process is repeated for the next sampling period.

A computer simulation representing the control strategy will be presented in the next chapter.

CHAPTER III

COMPUTER SIMULATION OF THE CONTROL STRATEGY

A computer simulation of the system shown in the block diagram in Figure 2.1 was developed to determine the simulated response for different values of the gains K_p , K_i and K_d . The program "Simash", listed in Appendix C, was developed using the basic programming language on the Hewlett Packard 9845B computer system.

Digital Modeling

The PID transfer function can be implemented on a digital computer using the following lines of Basic code :

```

10 I=I+E*T
20 D=Kd*(E-E1)/T
30 E1=E
40 U=K1*E+K2*I+D
50 Do control relative to U
60 goto 10

```

The derivative and integral expressions are simple finite difference approximations of these functions as used in the simulation. Lines 1300-1320 of the program "Simash" contain the code for the PID control algorithm

where:

- X= error signal ($T_h - T_{sys}$) in millivolts
- V= integral
- V1= the previous value of the integral
- X1= the previous value of the error signal
- Ps= power set
- K_p = the proportional gain
- K_i = integral gain
- K_d = derivative gain
- $K_3 = K_p$
- $K_2 = K_i/K_p$
- $K_1 = K_d/K_p$

This digital representation of the PID transfer function is a good approximation of the continuous PID transfer function used in theory.

In order to keep the rheostat from adjusting past its physical limits, the nonlinear function shown in Figure 1.2 is used to adjust the variac. The nonlinear function is called an on/off controller with hysteresis and dead band. The function of this controller is to adjust the variac if the value of the rheostat adjustment exceeds ± 15 windings. Should the rheostat exceed this limit, then the variac is adjusted by either 1 or 5 increments per sample period. The variac will be adjusted ± 5 increments per sample period if the absolute value of the temperature difference, X , is greater than 5 millivolts, otherwise the variac is adjusted by a ± 1 increment per sample period. The flowchart for this non-linear control function can be found in Appendix C. Lines 1400-1460 and 1700-1790 contain the Basic code for the implementation of the nonlinear variac controller.

The digital model for the transfer function:

$$\frac{Ke^{-sT}}{\tau s + 1} \quad (8)$$

can be determined by examining the finite difference representation for the function. If we consider $P(s)$ to be an input into the transfer function and $X(s)$ to be the output then:

$$X(s) = \frac{Ke^{-sT}}{\tau s + 1} * P(s) \quad (9)$$

Multiplying both sides by $\tau s + 1$ yields:

$$\tau s X(s) + X(s) = Ke^{-sT} * P(s) \quad (10)$$

Taking the inverse Laplace transform of the equation:

$$\tau \frac{dx}{dt} + x(t) = K * P(t-T) \quad (12)$$

using the finite difference representation for the derivative term and letting $k=kt$:

$$\frac{\tau}{H} (x(k+1)-x(k)) + x(k) = K * P(k-T) \quad (13)$$

Let $n=nH$, where H is the sampling rate, and rearranging yields:

$$x(k+1) = x(k) - \frac{H}{\tau} x(k) + \frac{KH}{\tau} * P(k-n) \quad (14)$$

Redefining the variables for the Basic computer language by letting:

$$\begin{aligned} x &= x(k+1), \text{ current value of } x \\ x1 &= x(k), \text{ previous value of } x \\ A &= H/\tau \end{aligned}$$

the equation becomes:

$$x = (1-A) * x1 + A * K * P(k-n) \quad (15)$$

The function $P(k-n)$ is the time delay and can be modeled by simply shifting an array in time. As represented in lines 1610 - 1630 of program "SIMASH", $P(k - n)$ can then be replaced by $P(Td1)$ where $Td1$ is the time delay between the heater and the temperature difference sensor. The total equation is therefore:

$$x = (1-A) * x1 + A * K * P(Td1) \quad (16)$$

Line 1520 is the model for the temperature rise Th and is based on a gain $K6$ which is a conversion from power to temperature.

The integrals in the simulation are modeled using:

$$Tr = Tr + Dr * H \quad (\text{see line 1340})$$

$$Tv = Tv + Dv * H \quad (\text{see line 1470})$$

The expressions are finite difference approximations. The power relationship is calculated in line 1510 where:

$$P(0) = R1 * Cv^2 * (Tv + 115)^2 / (R1 + Cr * (Tr + 20))^2 \quad (17)$$

In order to properly begin the simulation of the system, it is necessary to initialize the output of all of the integrals in the system. The values of x , P_{set} , Tr and Tv also need to be initialized. It is also necessary to initialize the time delay array. See the initialization section of the simulation program in Appendix C.

To establish parameter values for pure time delay, T , and the time constant, τ , for the simulation response, it was necessary to evaluate the response of the system to step change in the power to the control heater. Figure 3.1, shows the response to a step change in power to the control heater. The time delay was determined to be about 6.5 seconds while the time constant of the system was approximately 16.6 seconds for a flow rate of .5 gpm. Using the program "Simash", a suitable set of PID control gains were obtained by observing the responses for a number of values of K_p , K_i and K_d . A prompt, stable response was obtained for a flow rate of .5 gpm for the gain values:

$$\begin{aligned} K_p &= 3.0 && \text{the proportional gain} \\ K_i &= 0.3 && \text{the integral gain} \\ K_d &= 0.01 && \text{the derivative gain} \end{aligned}$$

Figure 3.2 is a plot of the response for those gain value at an initial value of T_h equal to 0. The simulation indicates that for a cold start

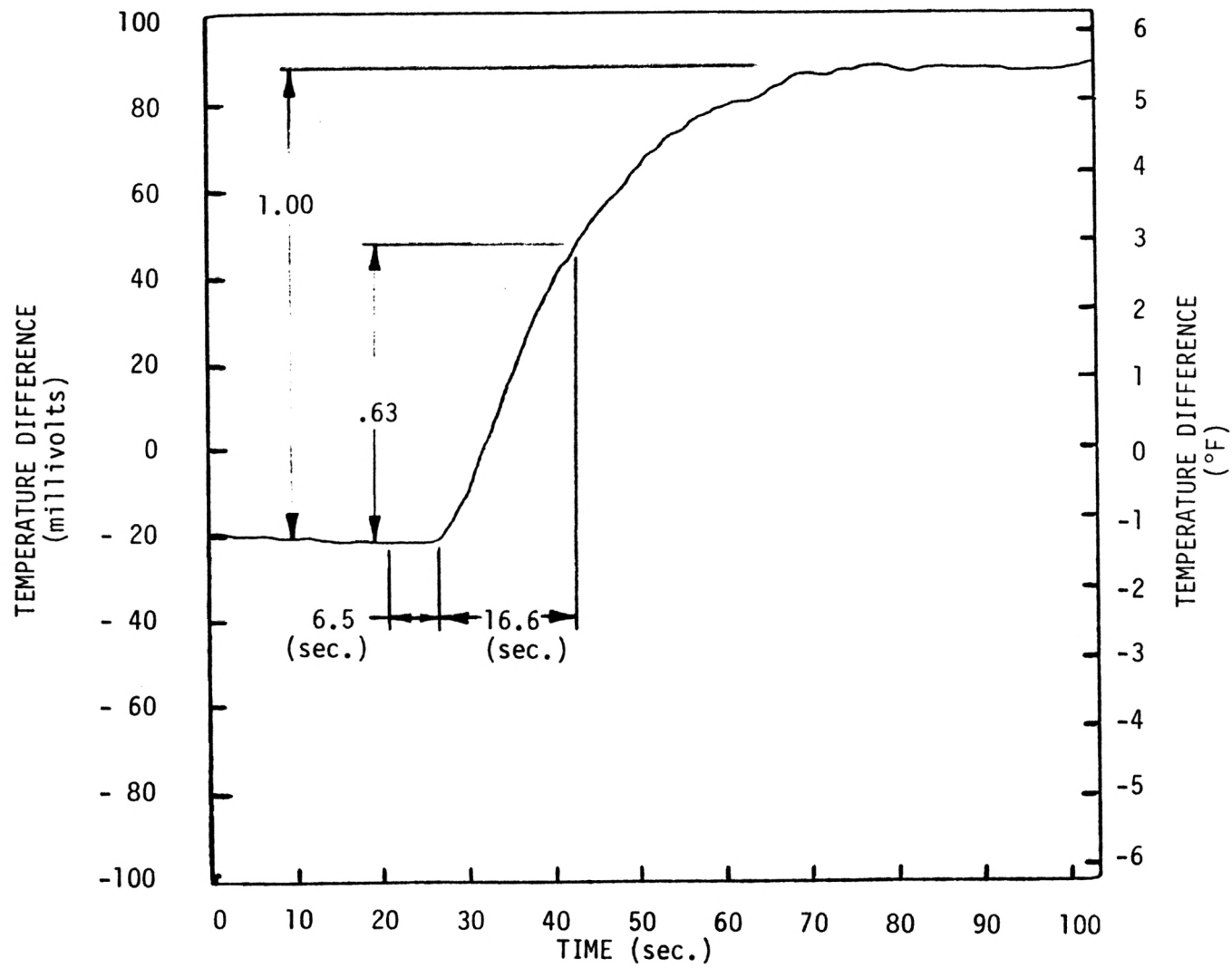


Figure 3.1
Step Response *

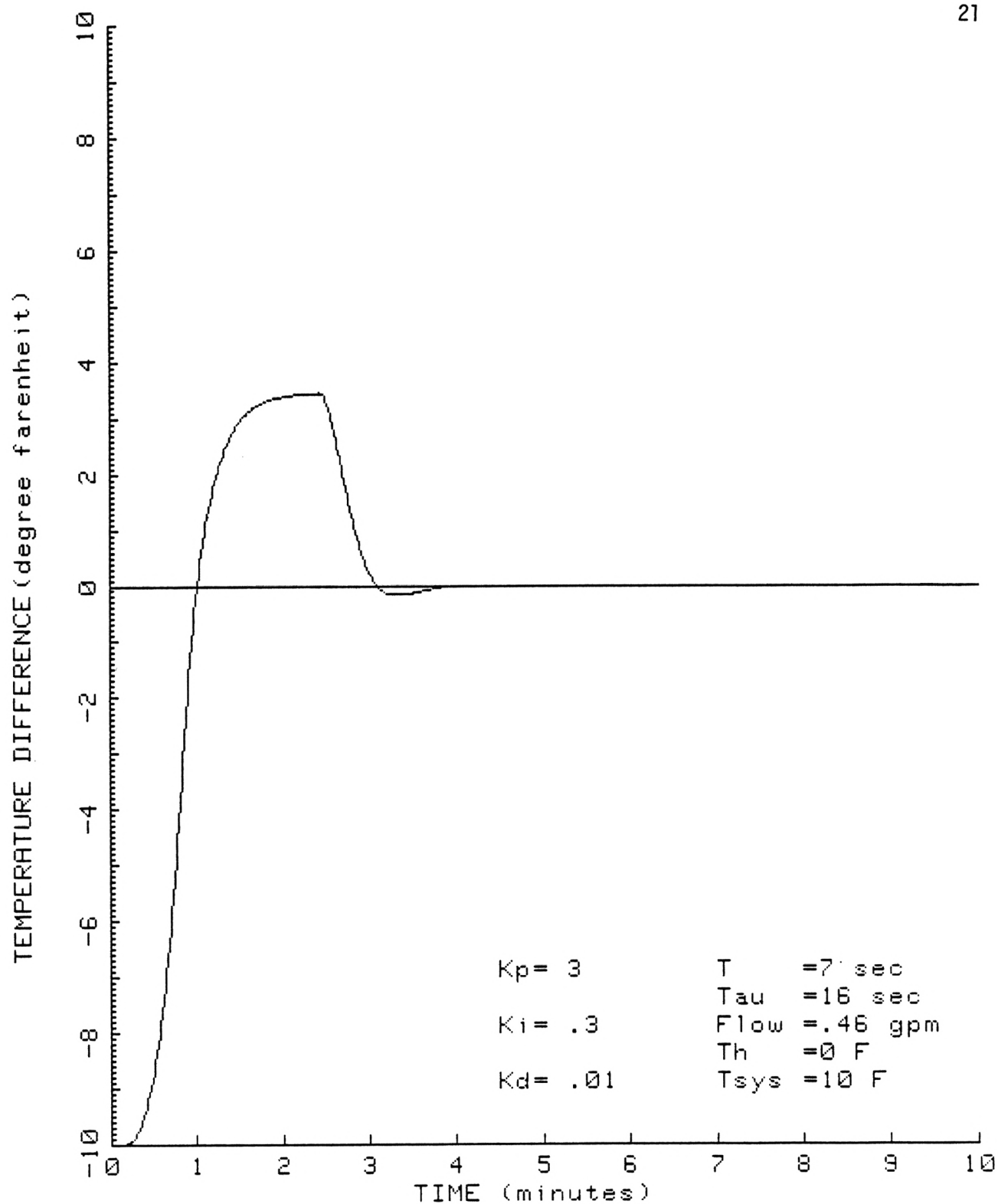


Figure 3.2
Simulated Response for $T_h = 0$

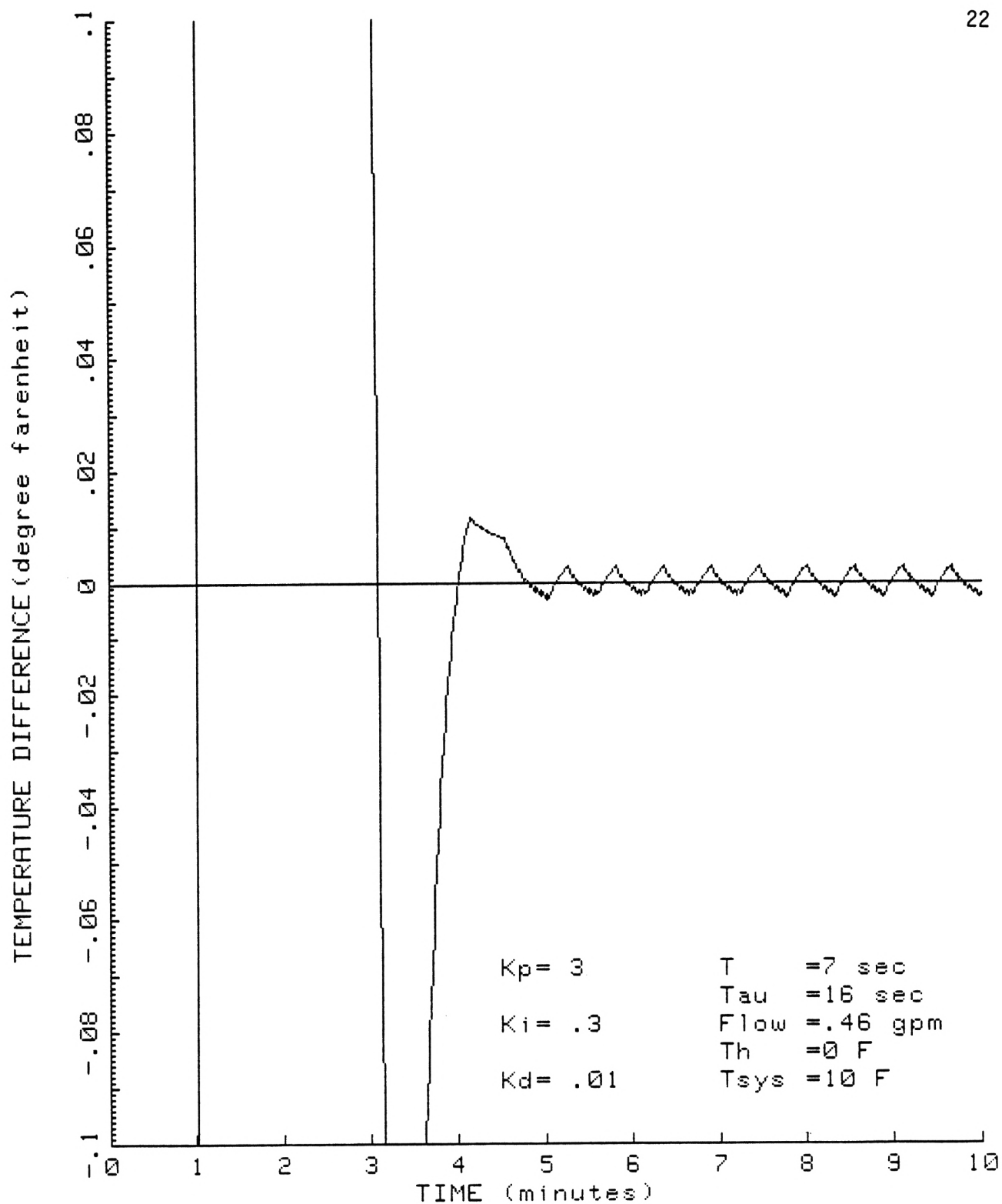


Figure 3.3

Simulated Response for $T_h = 0$
(expanded view)

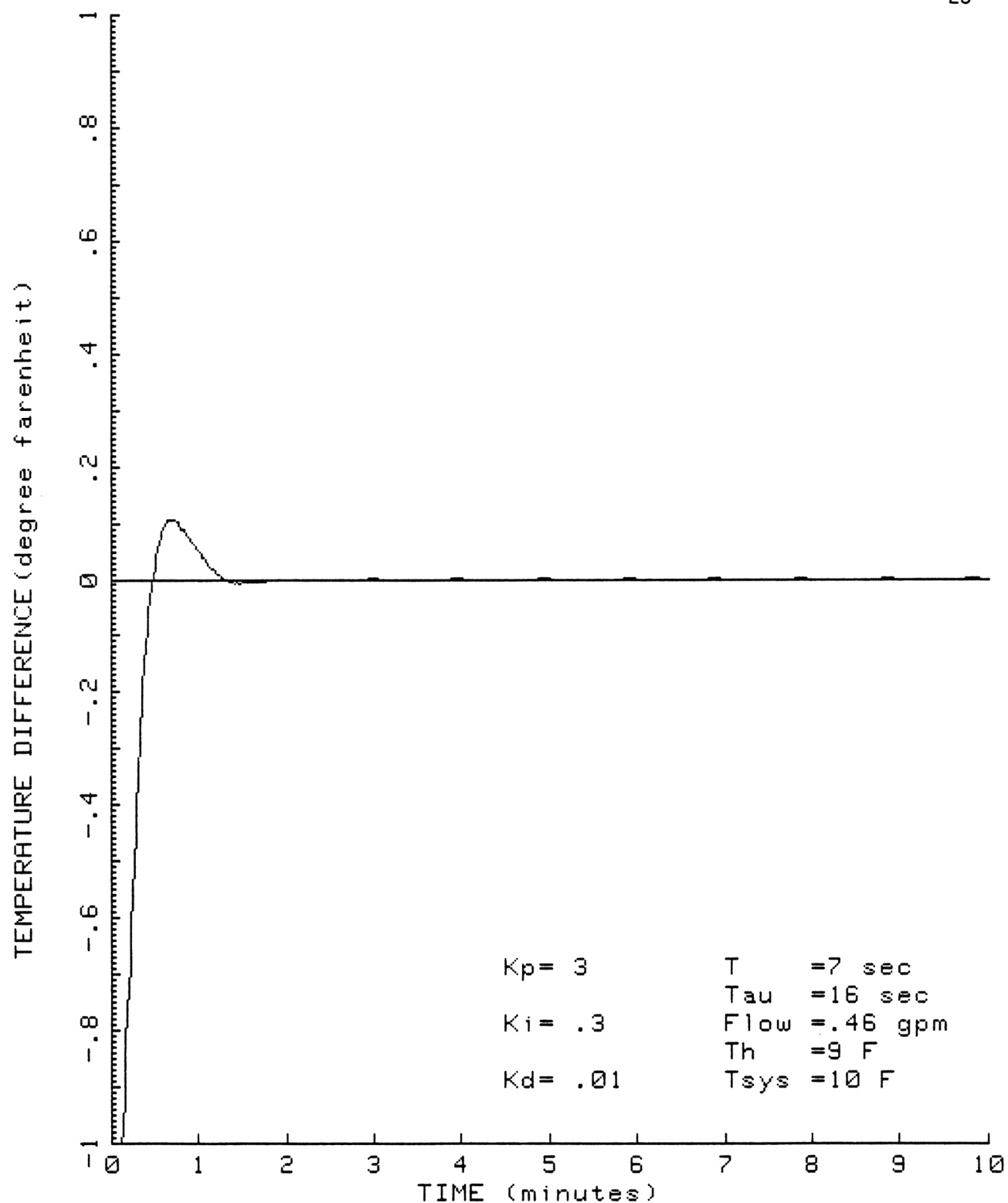


Figure 3.4
Simulated Response for $T_h = 9$ degrees

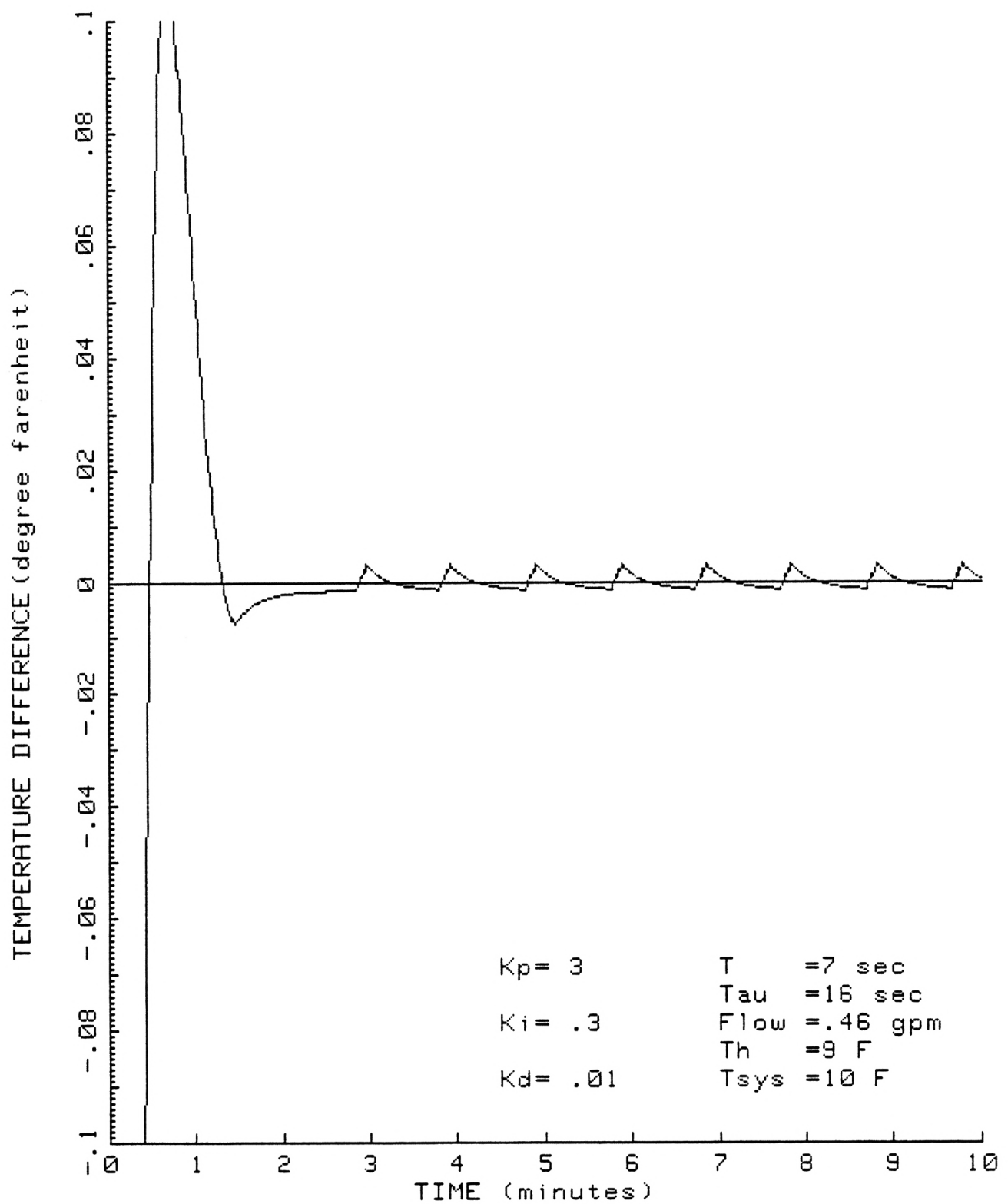


Figure 3.5
Simulated Response for $T_h = 9$ degrees
(expanded view)

situation it will take the control system approximately 4 minutes to bring the response to a steady state value. Note that the overshoot is approximately 3.5 degrees Fahrenheit and that the curve is not entirely smooth. The response reaches a steady state value which reflects the maximum power input into the system. The response stays at a relatively constant level until the controller causes the variac to adjust back within its limits. It is this sudden adjustment in the power which produces the discontinuity. Figure 3.3 is an expanded view of Figure 3.2. The periodic wave form that exists during steady state operation is due to the discrete nature of the rheostat. This figure indicates that the rheostat chosen for the system is only sensitive enough to get the response to within ± 0.005 degrees Fahrenheit. Figure 3.4 and Figure 3.5 illustrate the simulated response for a T_h value of 9 degrees and a T_{sys} value of 10 degrees. These figures indicate that the temperature difference between the two flow paths will become zero in approximately 1.5 minutes with an overshoot on the order of 0.1 degrees Fahrenheit.

In this chapter the development and evaluation of a computer simulation of the control system has been presented. The simulation was used to find suitable values of the controller gains and to evaluate the control strategy. The next chapter describes the testing of the physical system. The response of the system will be compared to the simulated response.

CHAPTER IV

TESTING THE CONTROL SYSTEM

The test setup used to verify the control system is shown in Figure 1.2. The purpose of this experimental test system is to evaluate the control strategy described in Chapter II. The test setup is similar to the final system design. The components of the experimental setup include: the chiller, an isolation heat exchanger, two flow control valves, the calibration heater, the control heater, and the temperature difference transducer. Two turbine flow meters were also incorporated in the test setup and were used to monitor relative flow conditions. The voltage to the calibration heater can be adjusted by manually positioning a 0-280 volt variac.

It was determined that in order to effectively test the control system, the temperature difference across the calibration heater should be adjusted to about 10 degrees Fahrenheit. To obtain this temperature difference, the flow rates through the calibration heater and the control heater were adjusted according to the relationship:

$$\dot{m} = q/C_p \cdot dT \quad (18)$$

where \dot{m} is the flowrate
 q is the power to the heater
 dT is the temperature difference across the heater
 C_p is the specific heat of the liquid

The flow rates for various power settings and temperature differences can be computed for each of the heaters. The control heater, with a

resistance of 15.4 ohms, has a maximum power setting of 850 watts at a voltage of 114 volts. This maximum limit is determined by the boundaries that had to be set to keep the variac from trying to make adjustments near the ends. The flowrate through the control heater was determined by assuming that the power setting would operate near 730 watts and that the specific heat of the 20 percent glycol solution was equal to that of water. Using the above equation, the flowrate was calculated to be approximately .46 gpm. The flow rate through the calibration heater was estimated using the same procedure where the resistance of the calibration heater is 13.4 ohms and the voltage input was assumed to be 255 volts. The flow rate through the calibration heater was calculated to be approximately 3.3 gpm. Each of the flow rates were adjusted by alternatively pulsing each of the electrically actuated flow valves through software control (see Appendix A). The flow rates were measured for the individual flows at the isolation heat exchanger using a graduated cylinder and a stop watch. The final design will incorporate feedback from piston type flow meters and the flow rates will be adjusted automatically through software.

Six tests were run for a flow rate of .46 gpm through the control heater and a 3.3 gpm flow rate through the calibration heater to evaluate the control strategy. The first test, Test #1, was to observe the response of the system to a step change in power to the control heater. Test #2 was performed to determine the source of noise which existed in the system. Test #3 demonstrates the response of the system to a cold start. Test #4 was performed to determine if there was any zero offset. Test #5a illustrates the system's steady state operation and test #5b demonstrates the response of the control system to change in power to the calibration

heater.

Response of the System to a Step Change in Power to the Control Heater

When the flow rates had been adjusted, a step change in power was applied to the control heater. No power was applied to the calibration heater during this step response test. Figure 4.1 is a plot of the temperature difference transducers output voltage verses time for this test. A pure time delay of about 6.5 seconds was determined from the plot. This delay is due to the transport lag between the control heater and the temperature difference sensor. The time constant was determined from the graph by determining the time that it takes for the voltage to reach 63 percent of the steady state voltage. The signal from the temperature difference transducer is filtered by using an RC network. The time constant of the heater will include this RC time constant. The time constant was determined to be approximately 16.6 seconds. These two values along with a flow rate of .46 gpm were used in the computer simulation described in Chapter II. Note that the simulation includes the boundry limitations of both the rheostat and variac. Once the PID control value gains have been determined for the estimated flow rate, the control system could be implimented using the compiled basic computer program Ashrae14.Bas. See listing in Appendix C .

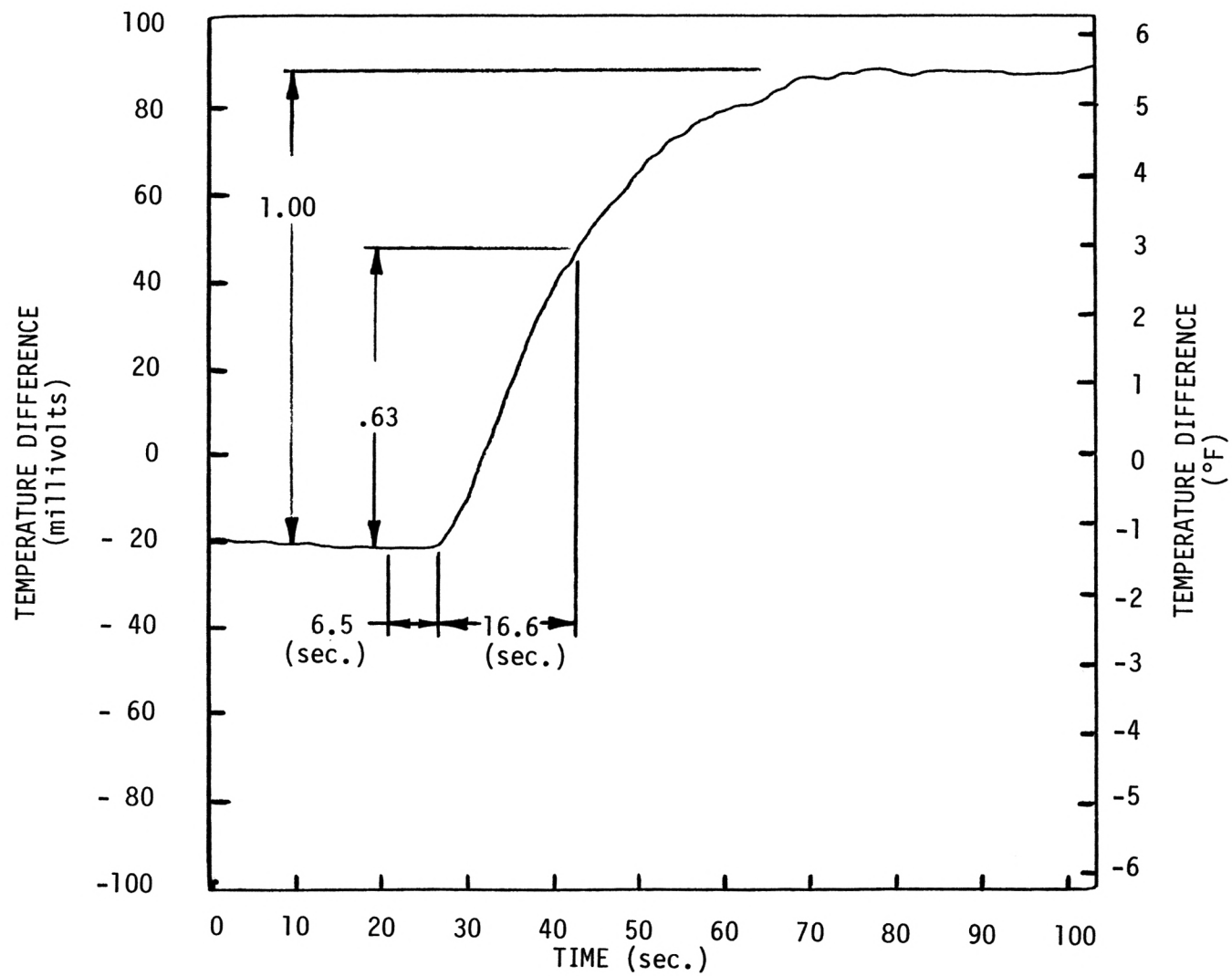


Figure 4.1
Step Response of Control Heater*

System Startup

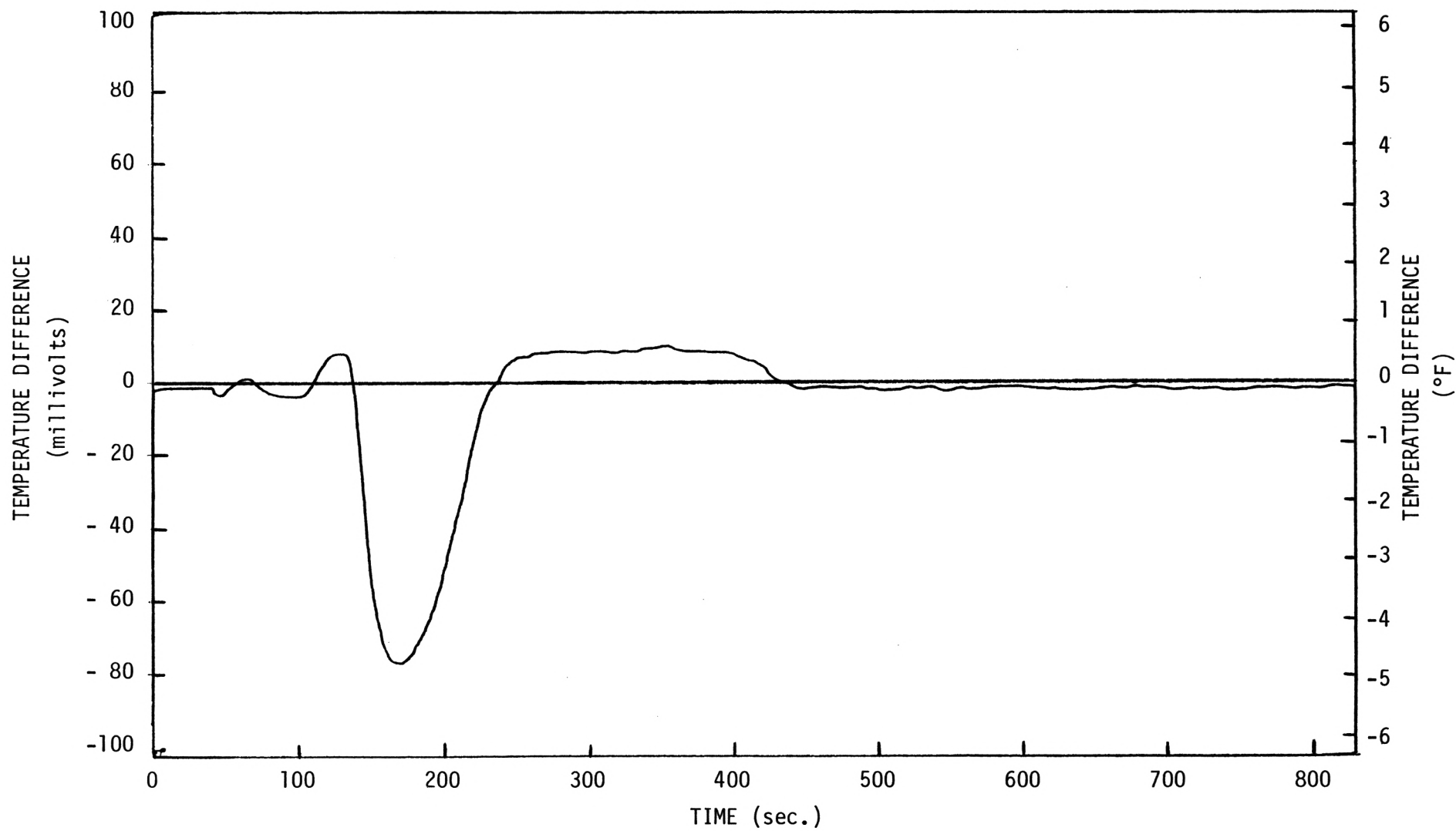
Figure 4.2 is a plot obtained using the digital oscilloscope during a system start up. The procedure for a startup is as follows:

1. Turn on the computer
2. Turn on oscilloscope to a sampling rate of 200 samples/sec
3. Make sure the control heater and calibration heater do not have power applied to them.
4. Run the compiled computer program Ashrae14.exe
5. Assuming the flow has been adjusted select the control menu
6. The program prompts the user to name a data file
7. Zero the variac and rheostat when the program prompts the user
8. Push the live button on the oscilloscope to begin data collection
9. Push the return key to begin control
10. From 0 to 20 seconds (steady state, no control)
11. At 20 seconds the circulation pump was turned on
12. At 40 seconds the chiller circulation pump was turned on
13. At 60 seconds turn on the chiller
14. At 80 seconds plug in the control heater
15. At 100 seconds turn on the calibration heater

Note, that the initial steady state value shown on the graph is not exactly at zero. When the graph was plotted on the x-y plotter, the oscilloscope was not zeroed properly before the graph was dumped to the plotter. The initial steady state value should be zero. This shift in the axes also indicates the final controlled steady state value is also very close to zero.

Thermal Noise

One of the problems that was encountered with the system was that of noise. One of the major sources of noise was determined from Figure 4.3. This figure shows the response of the temperature difference sensor when different parts of the system were turned on. The procedure for test 2 was as follows:



STARTUP TEST #5
Figure 4.2
Start up Response*

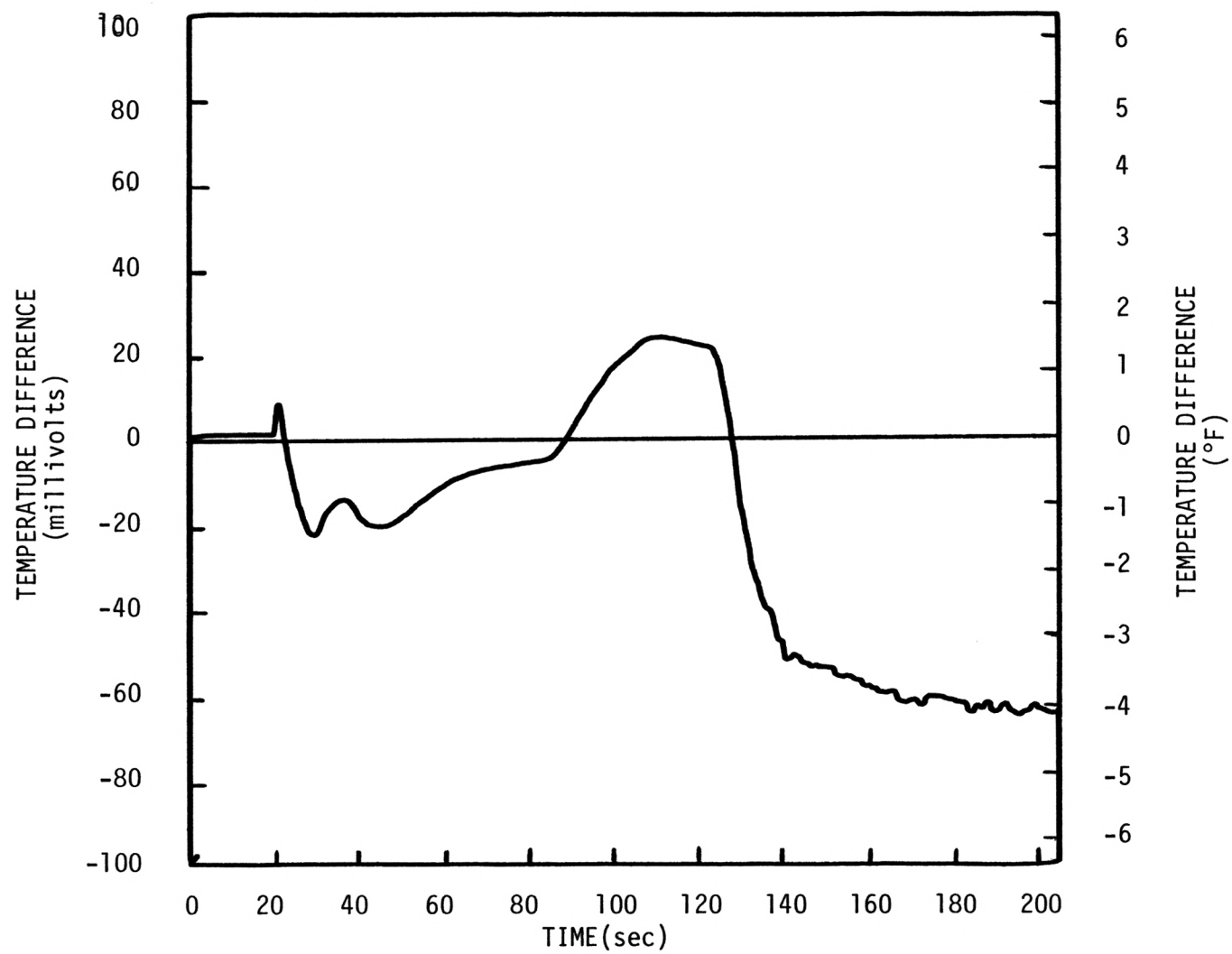


Figure 4.3
Determination of Noise*

| Time (sec) | Function |
|---------------|---|
| 0 | Start recorder |
| 20 | Start system pump |
| 40 | Start chiller pump |
| 60 | Start chiller compressor |
| 80 | Turn on control heater (full on) |
| 100 | Turn on calibration heater 1 (565 watts) |
| 120 | Turn on calibration heater 2 (3700 watts) |

The calibration heater used for this test has three heating elements. Initially, two of the elements were used to obtain the temperature difference across the calibration heater of 10 degrees Fahrenheit. The results shown on Figure 4.3 indicate that thermal noise from the calibration heater caused a response from the temperature difference sensor on the order of ± 4 millivolts. The system was inspected and it was determined that there was not enough volume between the calibration heater element and the temperature transducer to allow for even mixing of the heated fluid. In order to increase the volume between the calibration heat element and the temperature difference sensor, the heater was reversed so that the heating element was farther away from the temperature difference sensor. Calculations of the power for a single heating element indicated that the 10 degree temperature rise could be obtained using a larger variac and a single heating element. Reversing the heater and using a single heating element reduced the thermal noise to ± 2 millivolts. A mixing tank was then installed between the calibration heater and the temperature sensor. The thermal noise, as sensed by the temperature transducer and monitored with a digital oscilloscope, was reduced to the order of ± 1 millivolts.

Cold Start

The uncontrolled drift of the system is illustrated in the first half of Figure 4.4. The control system had been controlling the system for a period of two hours when the control system was shut off. Time 0 to 1000 represents a period of time when the system was allowed to drift with no changes in power to the control or calibration heaters. At time 1000 the power to the control heater was shut off and the controller was restarted at time 1015. Figure 4.5 is an expanded graph of the left half of Figure 4.4 from time 0 to 1008. Figure 4.6 is an expanded view of the right half of Figure 4.4 and demonstrates the systems response when the control system was restarted. The control system responded by causing the system to overshoot very much the same as in the simulated response of Figure 3.1. The computer control program, Ashrae14.bas includes the capability to store the measured voltage from the temperature difference sensor sequentially on a memory speed disk. The program uses and stores the average value of 10 samples taken during every one second cycle. The data is stored into a data file with a name that the user specifies during the initialization. Figure 4.7 is a plot of the data that was stored in the file test3.dat during the same time as when the oscilloscope data shown in Figure 4.6 was taken. A listing of this data can be found in the Controls Data File (see reference 3). The data file contains only the temperature difference transducer data expressed in millivolts. Other pertinent data was manually collected such as the control heater power, the bucket temperature, the calibration heater temperature difference, and the calibration heater voltage. Evaluation of recorded data indicated that the peak overshoot for the response, not shown on the graph, was approximately 11.5 millivolts

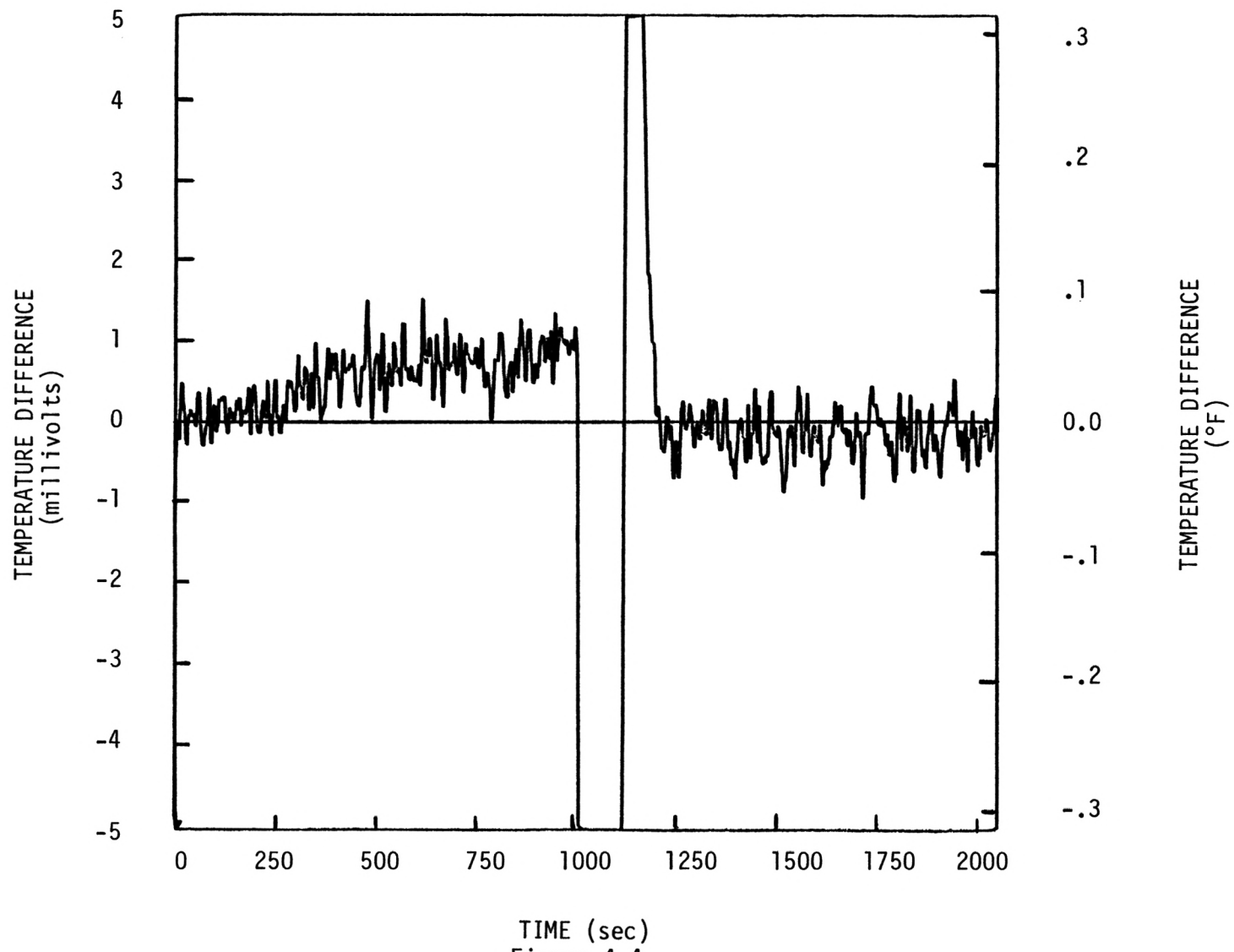
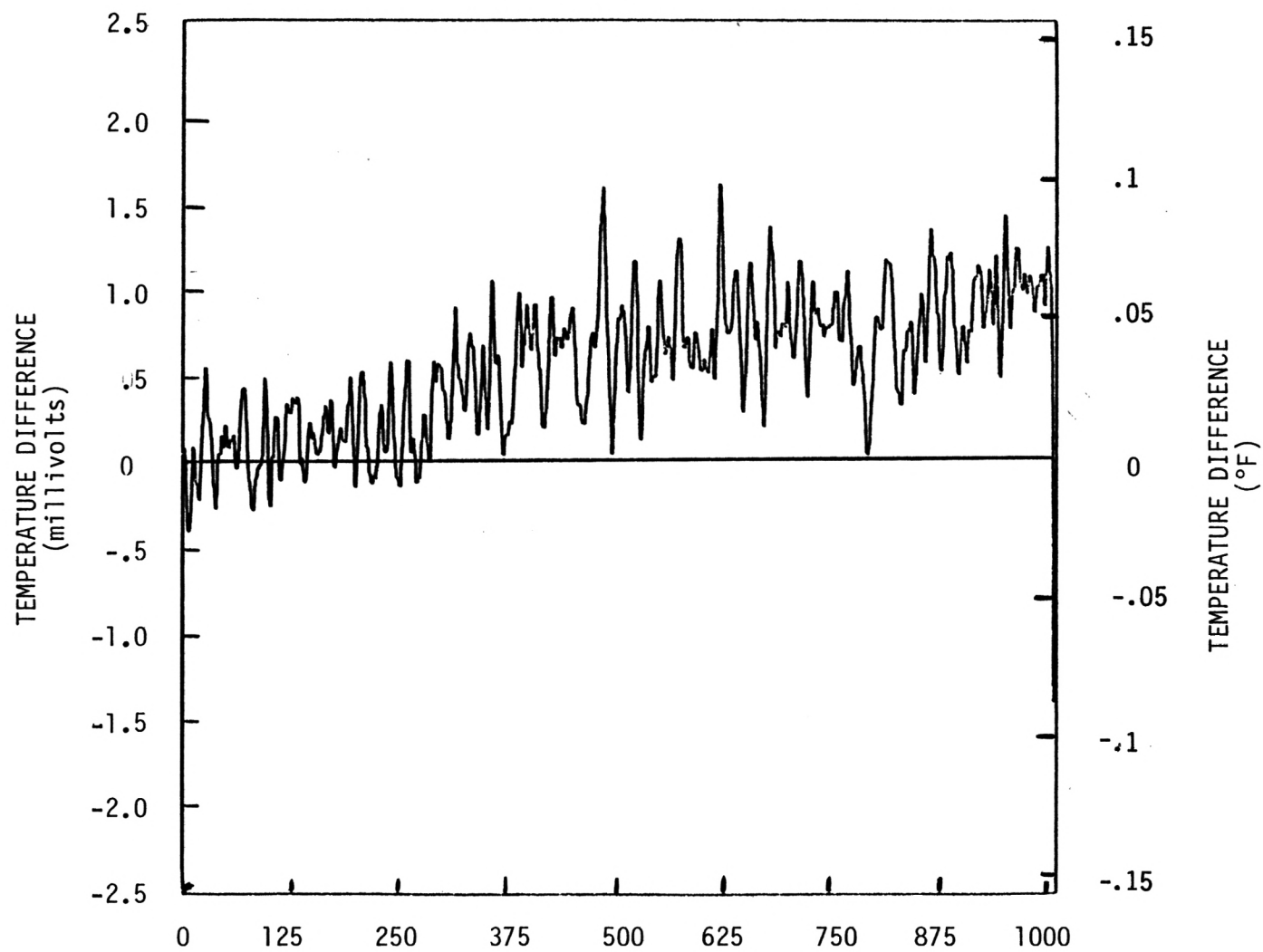
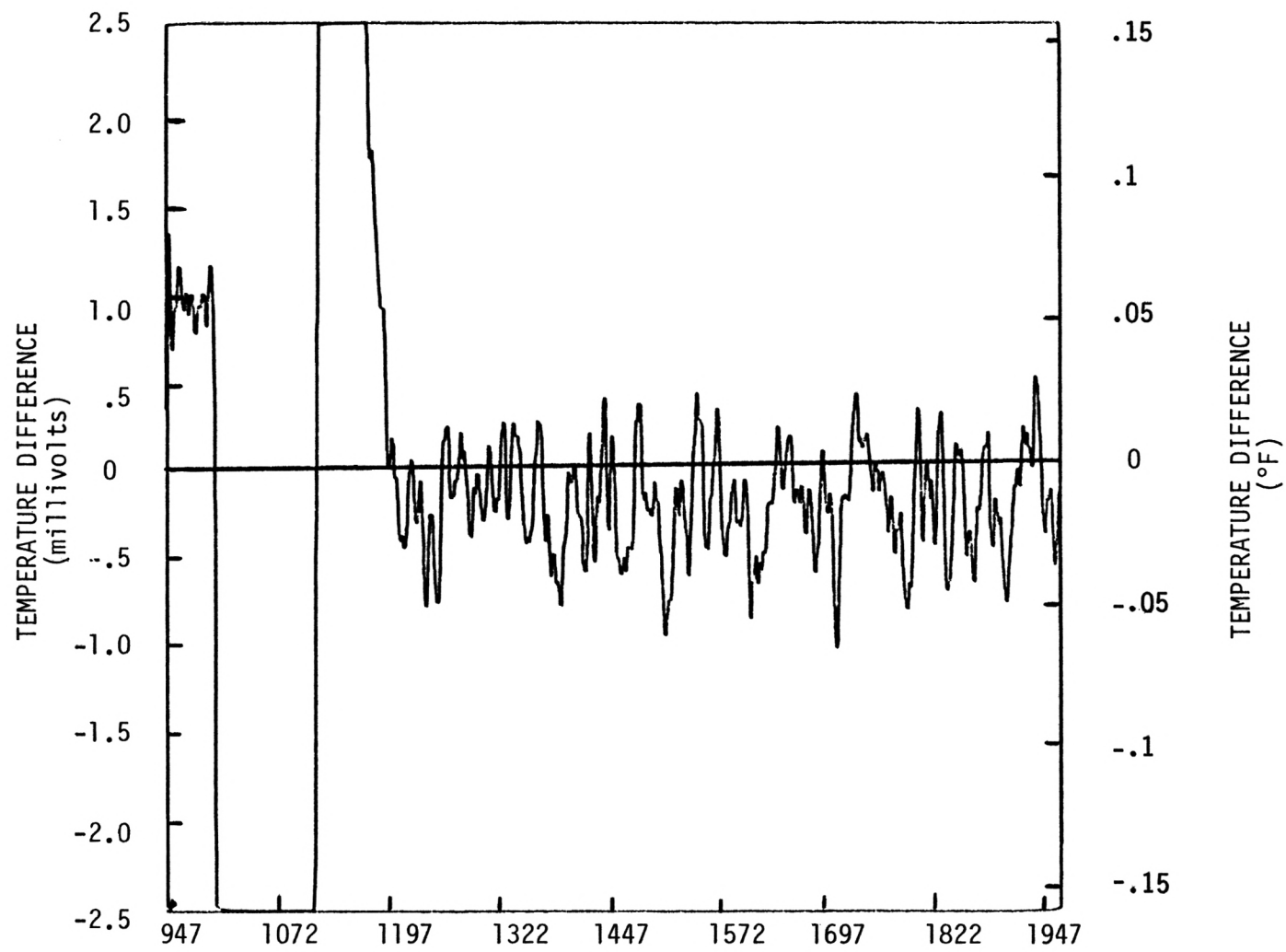


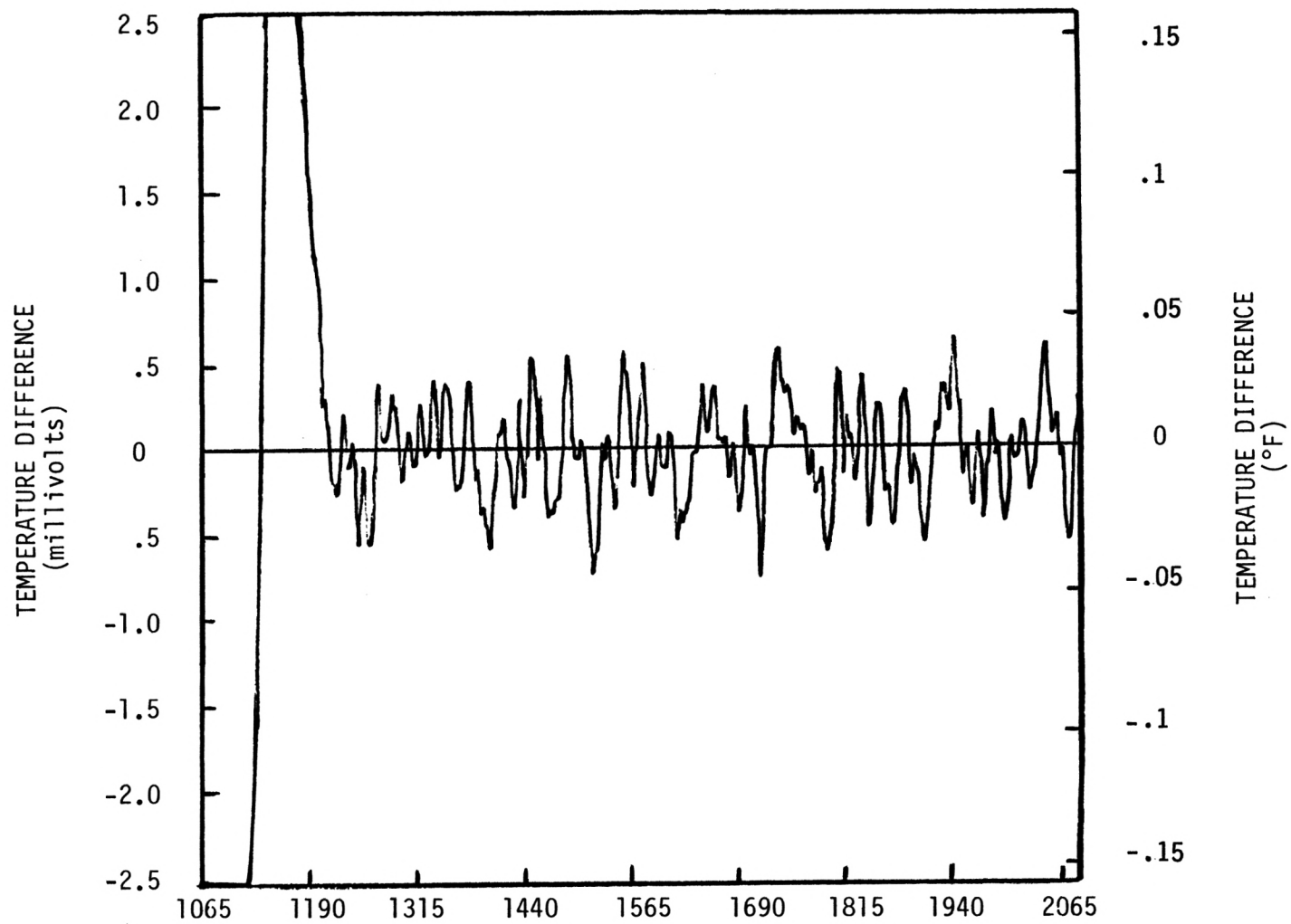
Figure 4.4
Cold Start*



TIME (sec)
 Figure 4.5
 System Drifting with No Control
 (expanded view of 4.4)*



TIME (sec.)
 Figure 4.6
 Restart Response
 (expanded view of 4.4)*



TIME (sec.)
Figure 4.7

Restart Response
**

which is less than 1 degree Fahrenheit. Note that graphs 4.6 and 4.7 are in very close agreement. Comparison of Figure 3.1 with either Figure 4.6 or Figure 4.7 indicates that the simulated results are comparable except for the thermal noise which exists in the real system. The difference in the two figures is that of thermal noise. The similarity of the two figures suggest that the computer simulation is a good representation of the real systems response and future changes in gain values, flow rates, or component sensitivities can be observed by changing their respective values in the computer simulation. The computer simulation can be used to determine the effect of any combination of these changes.

Zero Offset Test

A test was run to determine the mean and standard deviation for the output of the temperature difference sensor after a 12 hour no operation period. The data was obtained by running the program Ashrae14.exe with all of the heaters and pumps shut off for approximately 600 seconds. A Basic computer program named Mean.bas was developed to determine the mean and standard deviation for 3600 samples. The listing can be found in Appendix C. The program was then changed to allow for a 600 sample rather than a 3600 sampling period. The mean for this 600 second time period was calculated to be $-.01619$ millivolts with a standard deviation of 0.01775 millivolts. These values correspond to a temperature of about $.001$ degrees Fahrenheit and indicate that no significant zero error exists for the temperature difference transducer.

Steady State Test

A steady state test was performed to determine the average temperature difference for two consecutive hours of operation. The system was started after a 12 hour dormant period and it was determined that the system temperatures had settled after about 2000 seconds. Data was collected with control program Ashrae14.exe and was stored in a data file called Test5.dat. A listing of this data can be found in the Controls Data file. The mean and standard deviation were calculated for data representing two consecutive hours of operation. For the first hour period, 2200 seconds to 5800 seconds, the mean and standard deviation were calculated using the program Mean.bas. The mean for this hour period was found to be equal to 0.01227 millivolts (0.00078 deg F) with a standard deviation equal to 0.5469 millivolts (0.035 deg F). During the steady state operation the system temperatures remained relatively constant. The temperature difference across the calibration heater was approximately 10.26 degrees Fahrenheit and the bucket temperature was measured to be 104.36 degrees Fahrenheit. The ambient temperature during this time period did not change by more than +/- .9 degrees Fahrenheit.

The mean for the next hour period, 5800 to 9400 seconds, was calculated to be 0.01209 millivolts (0.00077 deg F) and the standard deviation was 0.33495 millivolts (0.021 deg F). Figure 4.8 is a plot which was taken with the oscilloscope at a 1 second sampling rate for the second hour period. Figure 4.9 is a plot which was generated from the computer data collected with the program Ashrae14.bas. The data was plotted with the program Plotv1.bas. The two graphs are so similar that it is very difficult to tell the two apart. Close examination of the two plots show

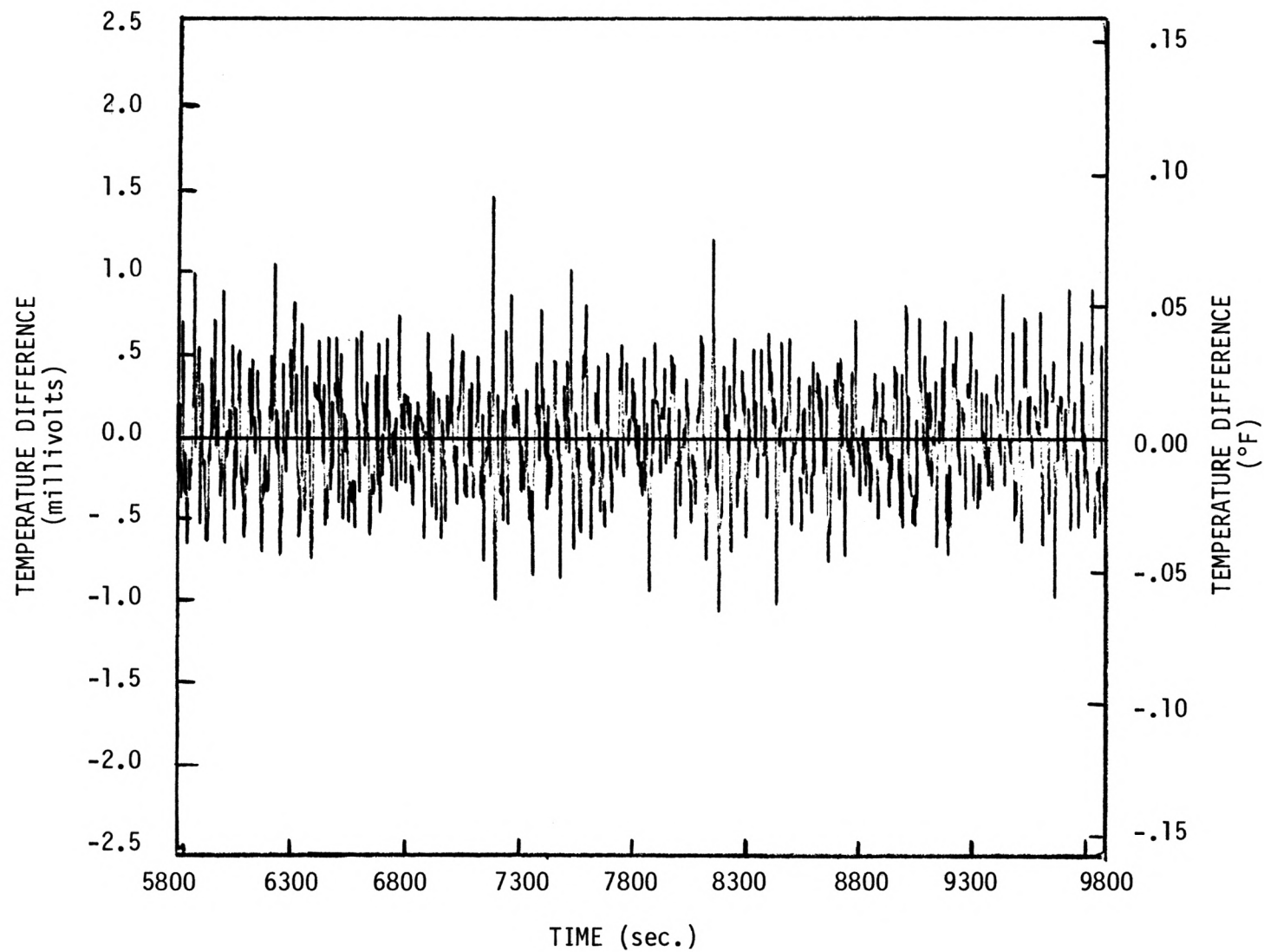
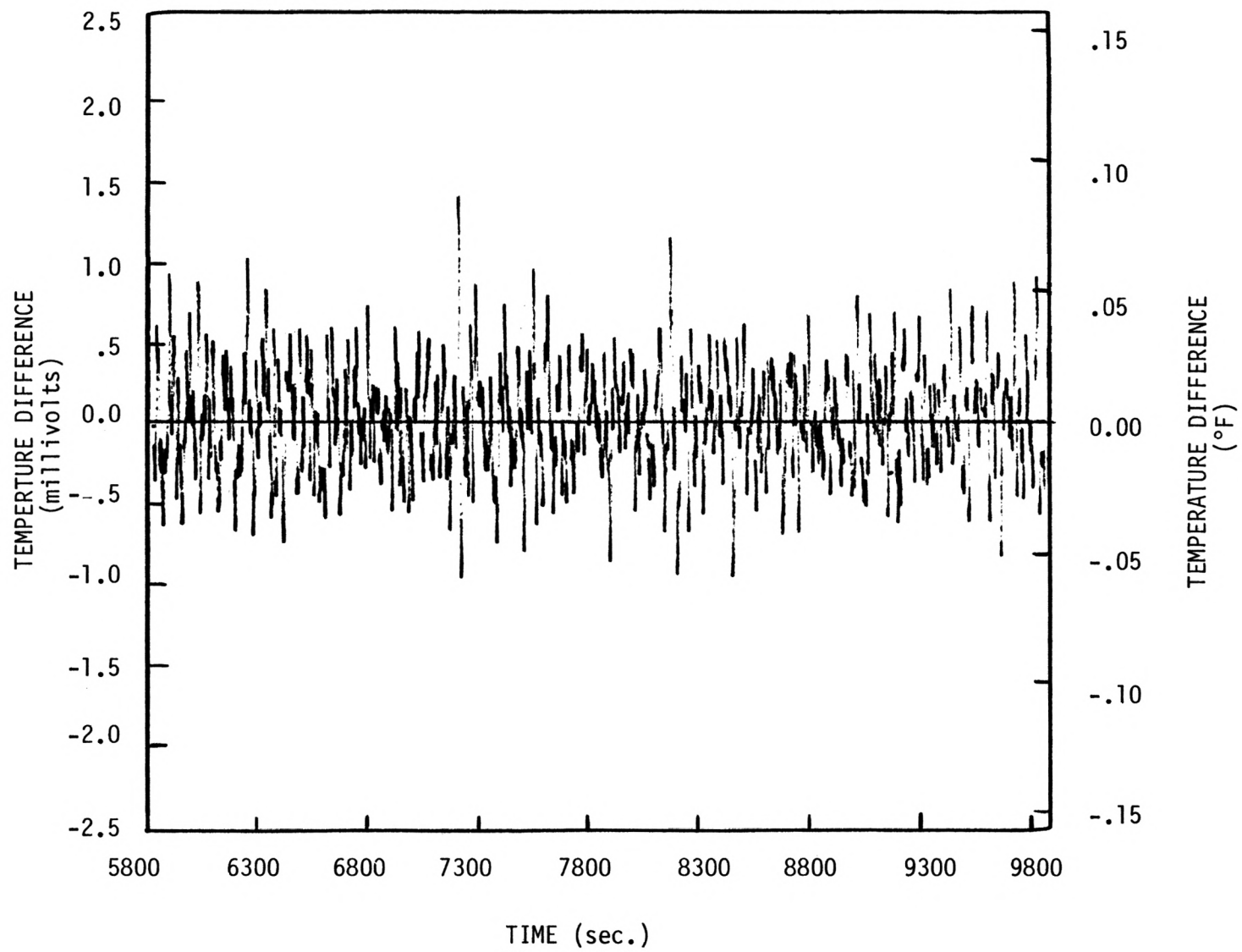


Figure 4.8
Steady State Response*



TIME (sec.)
Figure 4.9
Steady State Response**

that the peak-to-peak voltages are slightly less for the plot generated using the computer data. This is to be expected since each data point is representative of a 10 sample average.

Response to a Change in Power to the Calibration Heater

Following the steady state response test #5a, a test was run to show the systems response to a change in power to the calibration heater. The data was stored in the same file as test #5a and starts at time 12330. Figures 4.10 and 4.11 show at time the systems response as recorded by the oscilloscope and the control computer respectfully. At about time 12590 the power to the calibration heater was reduced from about 4300 watts to about 2900 watts by manually changing the variac setting. The reduction in power to the calibration heater reduced the temperature rise across the calibration heater, T_{sys} , from about 10.3 degrees Fahrenheit to about 7.6 degrees Fahrenheit. The peak of the response was approximately 21 millivolts or 1.3 degrees Fahrenheit. By changing T_{sys} from 10.3 degrees F to 7.6 degrees F caused the controller to change the power to the control heater from a power setting from about 670 watts to 415 watts. The results of this test indicate that the system can be controlled at different power settings for a given flow condition.

In this chapter a series of tests is described which show the performance of and permit evaluation of the control strategy. In the next chapter the results of these tests are summarized and conclusions and recommendations are given.

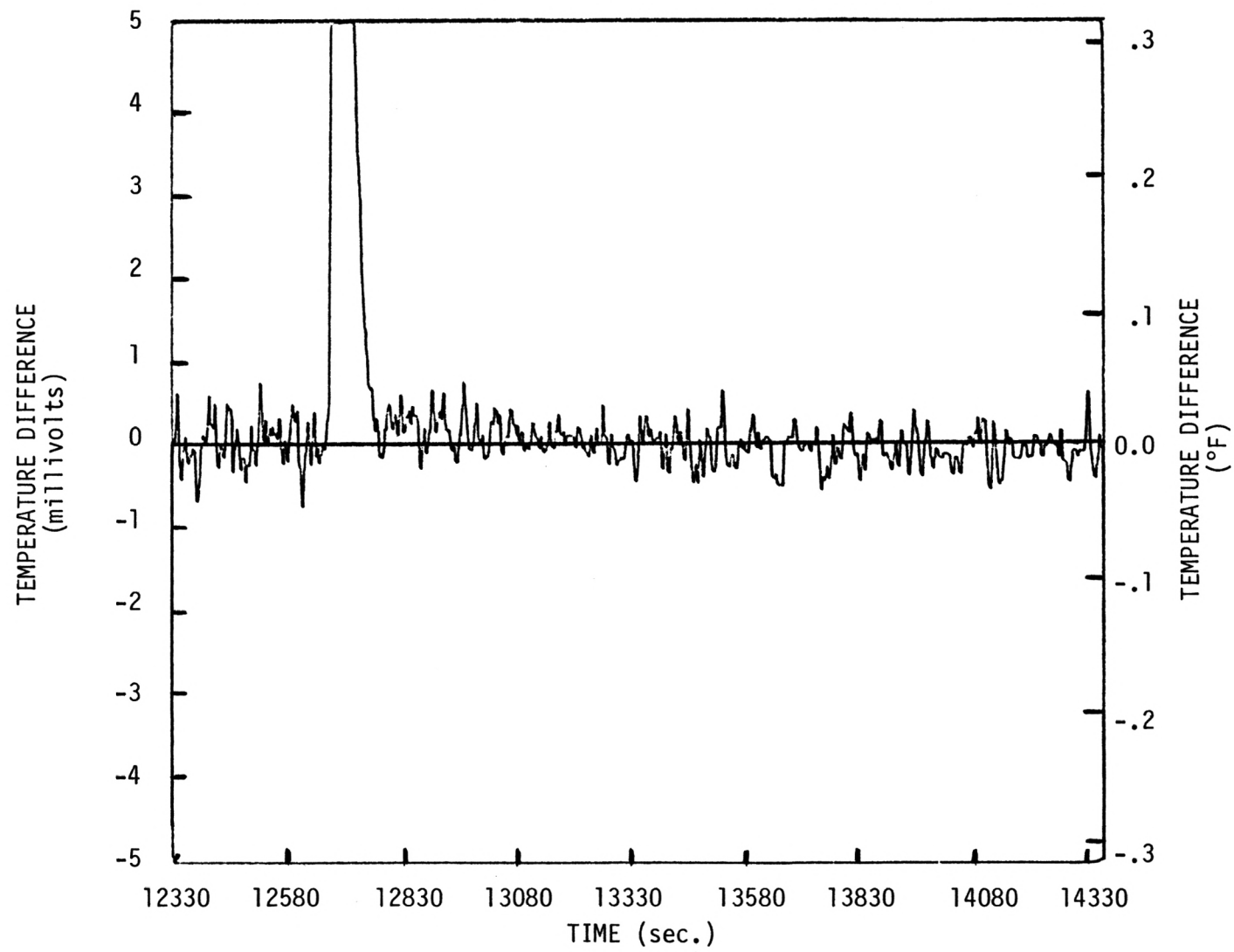


Figure 4.10
Response to a Change T_{sys}^*

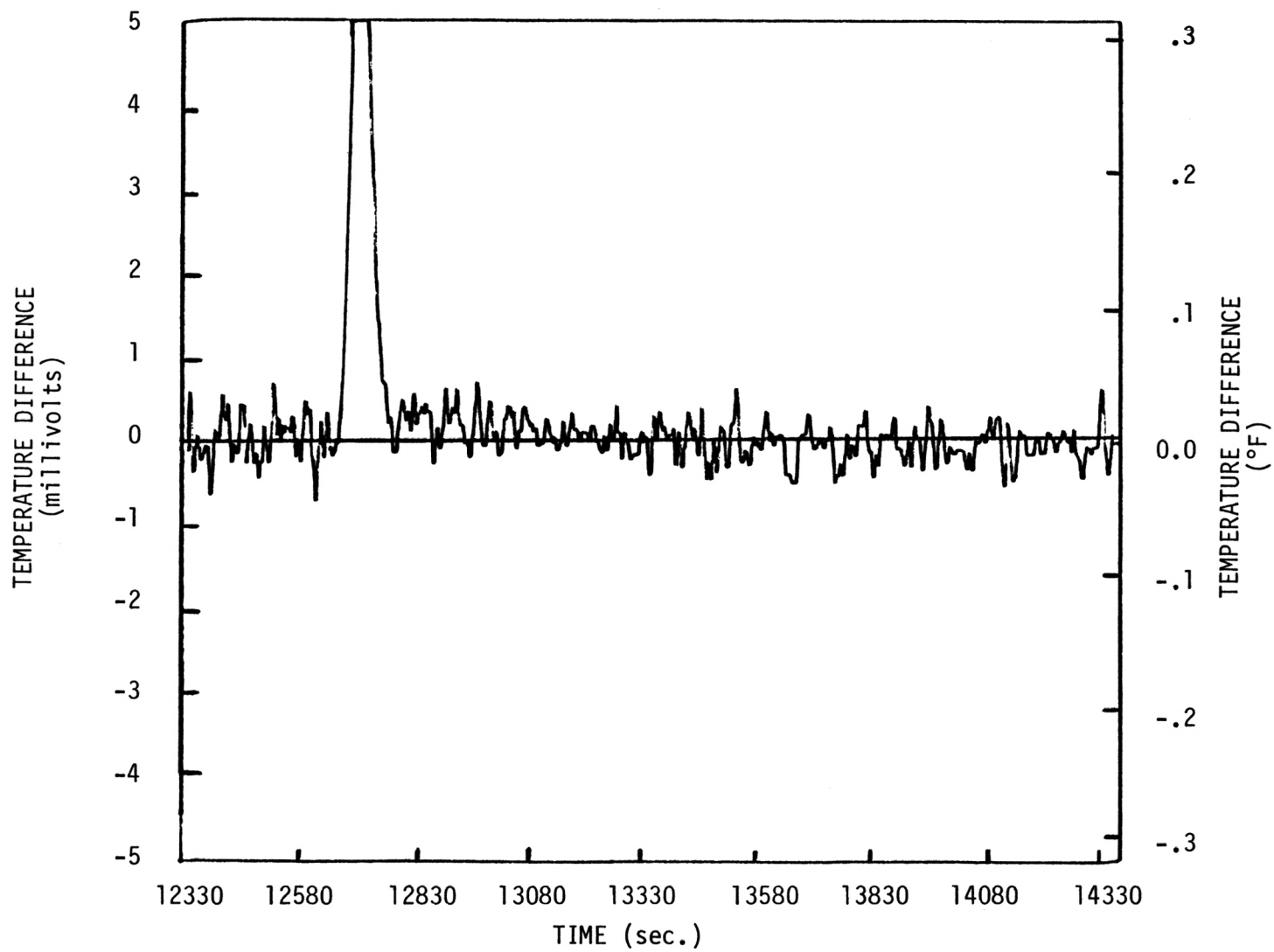


Figure 4.11
Response to a Change in T_{sys}^{**}

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Summary

This thesis has described a project to develop and evaluate a control system for a standard device for calibrating calorimeter rooms. The control strategy was developed in Chapter II and a simulation was developed and evaluated in Chapter III. The physical system was assembled and the control strategy implemented in the control computer. Testing and evaluation of the physical system was described in Chapter IV.

Conclusions

The following conclusions are summarized from this project:

1. The control strategy provides prompt, stable control of the system over a significant range of power levels.
2. The simulation is a faithful representation of the system.
3. The zero offset of the temperature difference measurement system is insignificantly small (about 0.001 degrees F).
4. The control system is able to maintain the average temperature difference within about 0.00076 degrees Fahrenheit over a time period in excess of one hour. This value is much better than the design goal of 0.006 degrees Fahrenheit.
5. The system exhibits a small amount of thermal noise with a standard deviation of about .03 degrees Fahrenheit over an hour time period and with maximum deviations on the order of 0.09 degrees Fahrenheit. The period of the thermal noise is 30 to 50 sec/cycle.

Recommendations

The following recommendations are provided for continuing this work:

1. Evaluate the sensitivity of the performance of the control system to flowrate to see if adjustments to the control gains K_p , K_d , K_i will be required for different flow rates.
2. Implement the flow meters and the control of the flow valves.
3. Include limit indicators to verify end of travel of the rheostat and variac and to provide for automatic initialization of the system.
4. Select a different rheostat for more sensitive fine control
5. Redesign the calibration heater to provide better mixing to reduce the thermal noise.
6. Implement the newly purchased Lab pac software to simplify and speed up the operation of the control algorithm and to provide additional data analysis capabilities.
7. Repackage the system to include the thermal guards and the heat exchanger.

The result of this project is a verified control algorithm for the control of a standard device for calibrating calorimeter rooms which provides prompt and stable control and exceeds the design specifications.

LIST OF REFERENCES

1. Beck, B. T., Jones, B. W., Thompson, J. G., A Standard device for Calibrating Calorimeter Rooms – Accuracy Determination, submitted for presentation to the 1985 ASHRAE Winter Meeting and publication in ASHRAE Transactions.
2. Controls Product File, Standard Device for Calibrating Calorimeter Rooms, 1984.
3. Controls Data File, Standard Device for Calibrating Calorimeter Rooms, 1984.
4. IBM Basic, Second edition, International Business Machines Corporation, 1981.
5. IBM Basic Compiler, First edition, International Business Machines Corporation, 1982.
6. IBM Disk Operation System, First edition, International Business Machines Corporation, 1983.
7. IBM Technical Reference Personal Computer XT, First edition, International Business Machines Corporation, 1981, 1982, 1983.
8. PC-mate Base Board, Tecmar Press.
9. PC-mate Expansion Chassis, Techmar Press.
10. PC-mate Stepper Motor Controller, Techmar Press.
11. Progress Report, A Standard Device for Calibrating Calorimeter Test Rooms, 344-RP, January 1983.
12. Progress Report, A Standard Device for Calibrating Calorimeter Test Rooms, 344-RP, May 1983.
13. Progress Report, A Standard Device for Calibrating Calorimeter Test Rooms, 344-RP, December 1983.
14. Progress Report, A Standard Device for Calibrating Calorimeter Test Rooms, 344-RP, April 1984.
15. Proposal to the American Society of Heating Refrigerating and Air Conditioning Engineers, A Standard Device for Calibrating Calorimeter Test Rooms, 344-TRP, May 28, 1982.

16. Techmar PC-mate Captain Installation Manual, Techmar Press.
17. Techmar PC-mate Lab Master, Installation Manual, Techmar Press.

APPENDIX A

HARDWARE DESCRIPTION

The power to the control heater is controlled by a stepper motor driven variac and a stepper motor driven rheostat. The wiring diagram for the power circuitry is shown in Figure 2.2. To calculate the power across the heater for this configuration we apply Ohms law, $V=IR$, and the definition of power, $P=I^2*R1$. The derivation of the power, P , defined in Chapter II is as follows:

$$P=I^2*R1$$

$$V_{line}=I(R_r+R1)$$

$$P0=V_v^2*R1/(R_r+R1)^2$$

$$V_v=C_v*T_v$$

$$R_r=C_r*Tr$$

$$P0=C_v^2*T_v^2*R1/(R1+C_r*Tr)^2$$

where

P =power across the control heater

$R1$ =resistance of the control heater

V_v =voltage of the variac

R_r =resistance of the rheostat

T_v =a positive # of windings on the variac

Tr =a positive # of windings on the rheostat

C_r & C_v are constants of proportionality described in Chapter II

The Motor Driven Variac

The variac chosen for the control heater is a Staccon Series 1010 Auto Transformer. In order to determine the type of stepper motor to be used to drive the variac, the following information about the variac had to be measured:

starting torque 10.5 oz in
 angle of rotation 342 degrees
 # of windings 230
 degrees/winding 1.487

The stepper motor chosen to drive the variac was a Rapid syn D.C. stepping motor, Model 23 H-502C. The specifications are as follows:

rated voltage 12 VDC
 .7 A/winding
 4 phase, 6 wire
 1.8 degrees, 200 steps/rev Full Step
 .9 degrees, 400 steps/rev Half Step
 Rated Torque 30 oz in @ 400 pulses/sec
 Maximum Pulse rate 600 steps/sec

In order to drive the variac it is necessary to run the stepper motor in a half step mode or .9 degrees per step. This will help to insure that the wiper on the variac can be positioned as close to each individual winding as possible without having to go through a gear reduction. For a stepping motor in the half step mode, the following sequence of power signals must be supplied to the individual coils as shown in Table 2.

| Step | Coils | | | |
|------|-------|---|---|---|
| | A | B | C | D |
| 1 | 1 | 0 | 0 | 1 |
| 2 | 1 | 0 | 0 | 0 |
| 3 | 1 | 0 | 1 | 0 |
| 4 | 0 | 0 | 1 | 0 |
| 5 | 0 | 1 | 1 | 0 |
| 6 | 0 | 1 | 0 | 0 |
| 7 | 0 | 1 | 0 | 1 |
| 8 | 1 | 0 | 0 | 1 |

Table 2

To reverse the stepping motor, one simply reverses the stepping sequence.

The Motor Driven Rheostat

The rheostat chosen for the fine control consisted of two 1.5 ohm Ohmite rheostats in parallel which will gave a 0 to .75 ohm resistance

range. In order to determine the type and size of the stepper motor which was to be used to drive the rheostat mechanism, the two rheostats had to be mounted in a parallel configuration so that the following information could be obtained:

| | |
|-------------------|-------------|
| starting torque | 20.25 oz in |
| angle of rotation | 324 degrees |
| # of windings | 41 |
| degrees/winding | 7.902 |

The stepper motor chosen to drive the rheostat was a Sigma Stepping motor, model # 20-2235 D. The specifications are as follows:

| |
|----------------------------|
| 5 VDC |
| 2 A/winding |
| 1.8 or .9 degrees per step |
| 120 oz in holding torque |

The rheostat is driven in the full step mode since the number of degrees per winding is 7.902 and the 1.8 degree per step will insure that the wipers on the rheostat can be positioned within each individual winding.

Figures 5.1 and 5.2 are the wiring schematic for driving the stepping motors. The control signals for either the full step mode or half step mode will be furnished by two separate CY512 stepper motor controller ICs located on the stepper motor controller expansion board. The 4 control signals are optically isolated using 4 4N33 opto isolators. The purpose of the isolation is to keep the ground of the computer and the ground of the power driving circuitry separated. The power is supplied to the individual windings by exciting the base of an NPN darlington power transistor. The transistor acts as a solid state switch by switching either the ground or the Vcc signal as is required by the control signals from the CY512. The

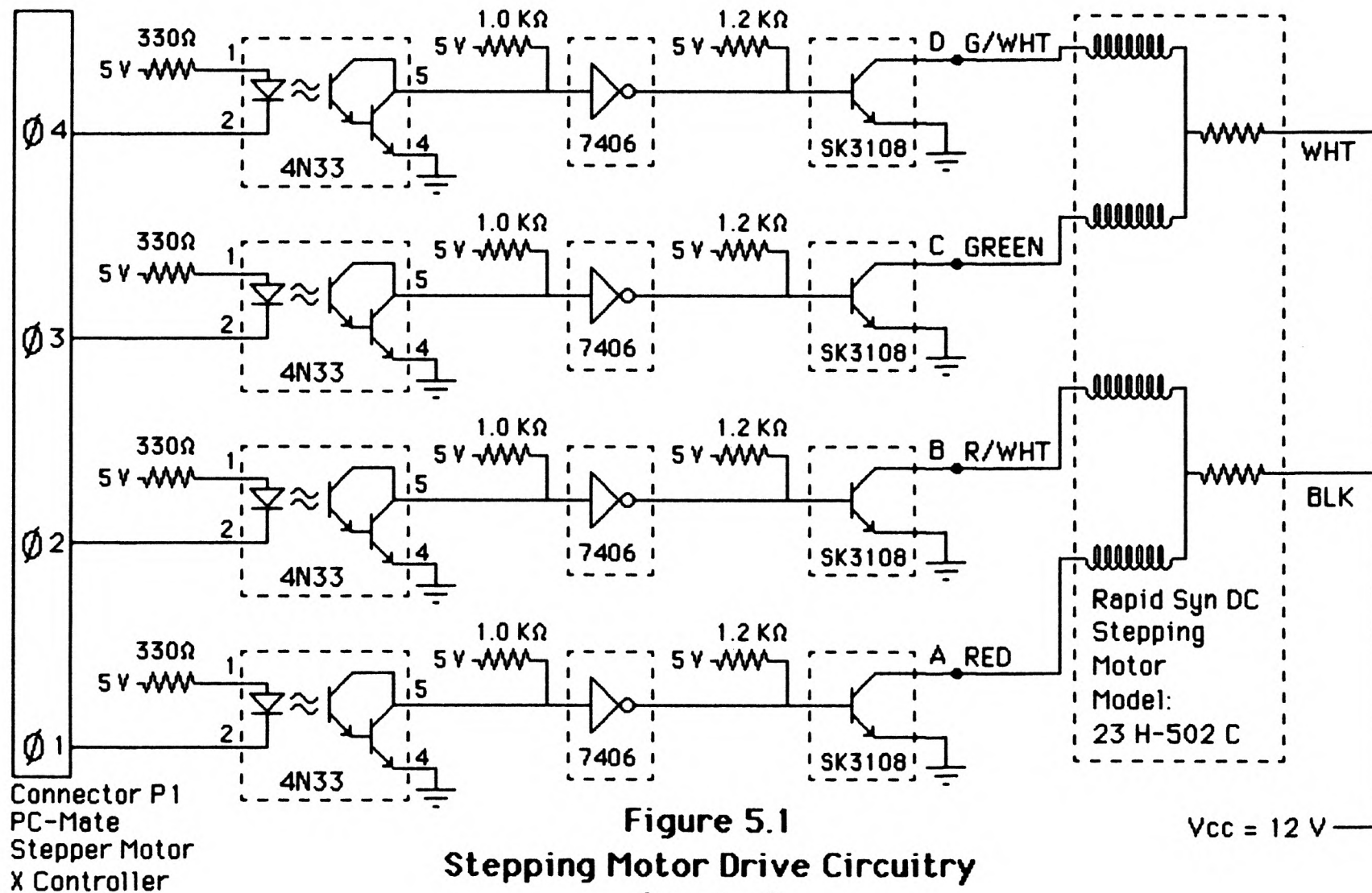
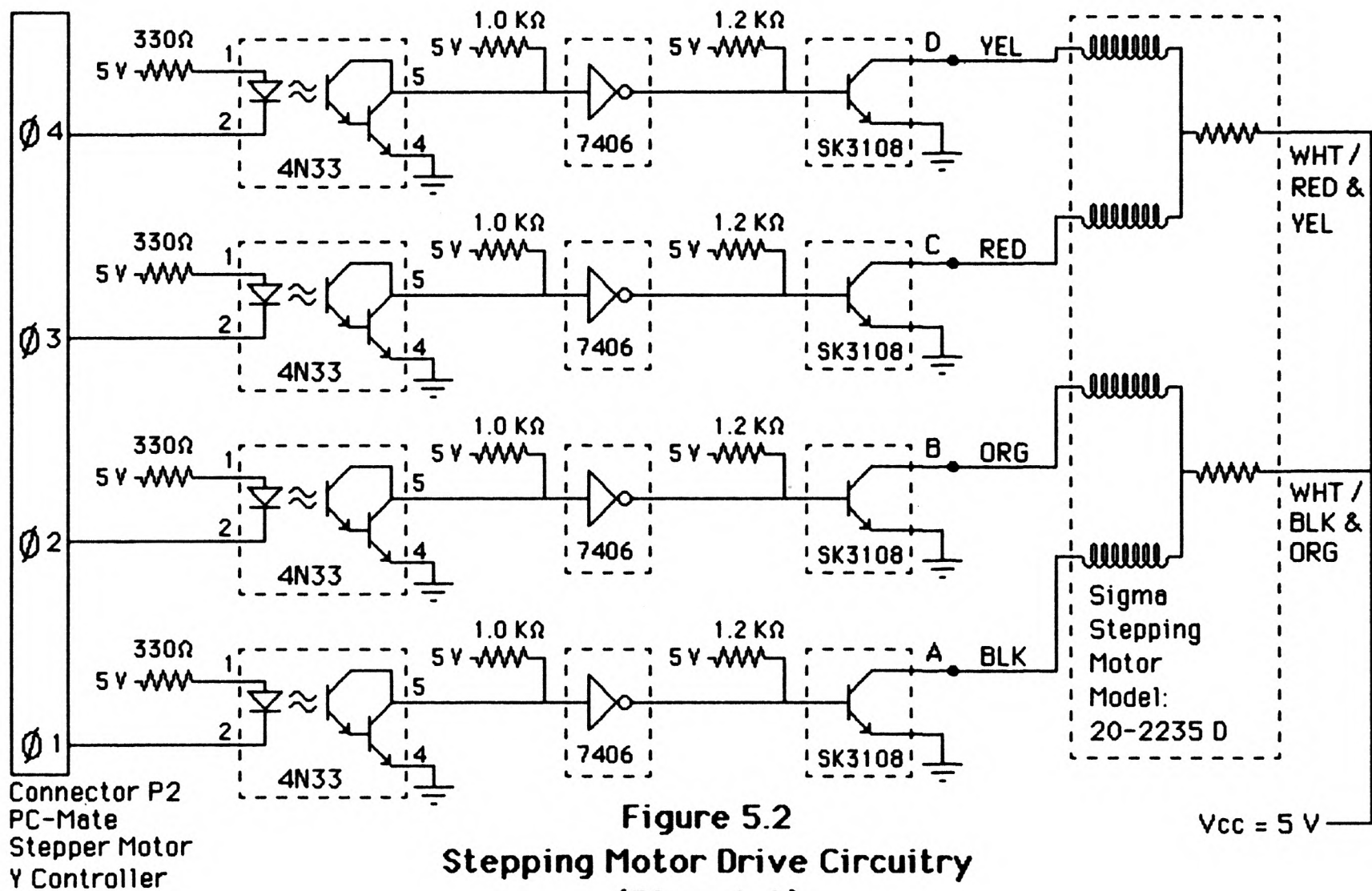


Figure 5.1
Stepping Motor Drive Circuitry
(Variac)



switching diodes shown are to help to eliminate voltage spikes and will allow the stepping motors to be driven at higher speeds. It should be noted that the opto isolation allows the power for the stepper motors to be separate from the power supply for the computer.

Controllability of the Rheostat and Variac

Assuming that the wipers may be positioned over each individual winding and that the position is discrete then for the rheostat:

$$.75 \text{ ohms}/41 \text{ windings} = .01829 \text{ ohms/winding}$$

and for the variac:

$$120\text{V}/230 \text{ windings} = .5217391 \text{ volts/winding}$$

In order to look at a single operating point of the rheostat and variac, operating points of 120 volts and .75 ohms were chosen. To verify that the rheostat has finer control of the power at these operating conditions, the relationship:

$$P = V^2 * R1 / (Rr + R1)$$

was evaluated for the operating points. If the power is evaluated for the set points above one obtains:

$$P = 120^2 * 15.4 / (.75 + 15.4)$$

$$P = 850.23 \text{ watts}$$

If the rheostat is stepped one winding, there is a change in resistance of 0.01828 ohm. Note that for a decrease in the rheostat resistance there is an increase in power for an increase in variac voltage there is an increase in power. For a correct comparison of the variac and rheostat, one must decrease the resistance and then increase the voltage. Increasing the resistance by 1 increment yields:

$$Pr = 120^2 * 15.4 / (.75 + .01828 + 15.4)^2$$

$$Pr = 848.3 \text{ watts}$$

Decreasing the voltage on the variac 1 increment yields:

$$Pr = (120 - .5217)^2 * 15.4 / (.75 + 15.4)^2$$

$$Pr = 842.81 \text{ watts}$$

The change of 1 increment of the rheostat represents 1.93 W/increment where the change of 1 increment of the variac represents 7.419 W/increment. The conclusions of this section is that with the variac and rheostat chosen for the project the finest we can control the power to the heater will be 1.93 watts. Using $q = m C_p dT$ and solving for dT

$$dT = q / \dot{m} C_p$$

and assuming water to be the operating fluid with a flow rate of .7 gpm yields a temperature change of:

$$dT = 1.93 / (1 * 8.323 * .7 * 60 * .293)$$

$$= \text{watts} / (\text{btu} / \# \text{ F}) (\# / \text{gal}) (\text{gal} / \text{min}) (\text{min} / \text{hr}) (\text{watt hr} / \text{btu})$$

$$dT = .0188 \text{ degrees Fahrenheit}$$

The Flow Control Valves

The flow control valves used in this project are ball valves driven by a Worchester series 75 Electric Actuator. The actuators are driven by AC motors through a gear train. The actuators are designed for on/off control of the motors. Through proper switching the actuators can be used to obtain a desired flowrate. Figures 5.3 through 5.6 are the schematics of the switching circuitry required to operate the valves. There are 3 valves in the system. Valve 1 operates the flow rate through the control heater. Valve 2 operates the flow rate through either the calibration heater or the heat exchanger. The third valve which will not be used in the test described in this thesis is a 3 way valve and diverts the flow either through the calibration heater or through the calorimeter room heat exchanger. The electric circuitry used for valves 1 and 3 are a solid

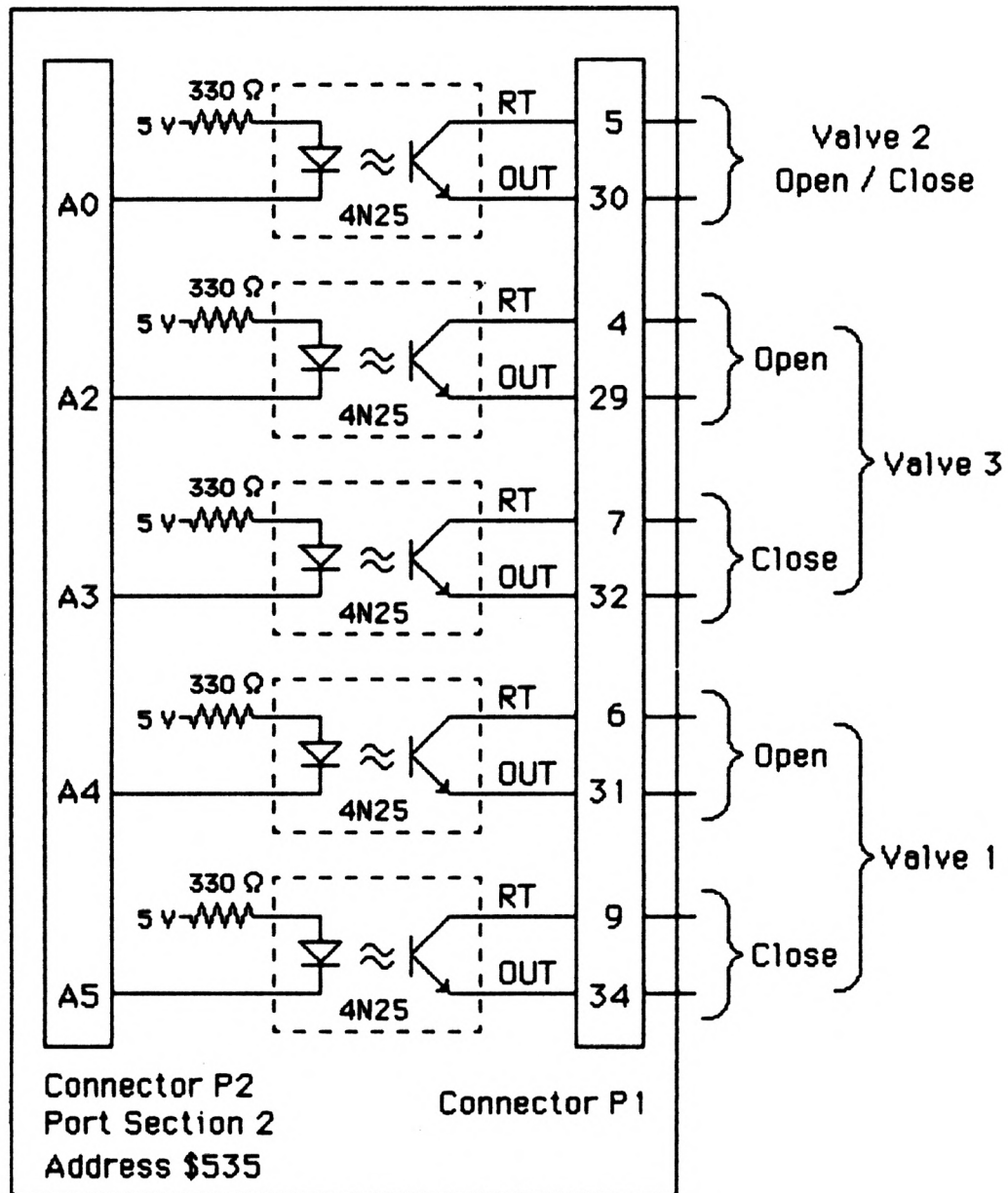
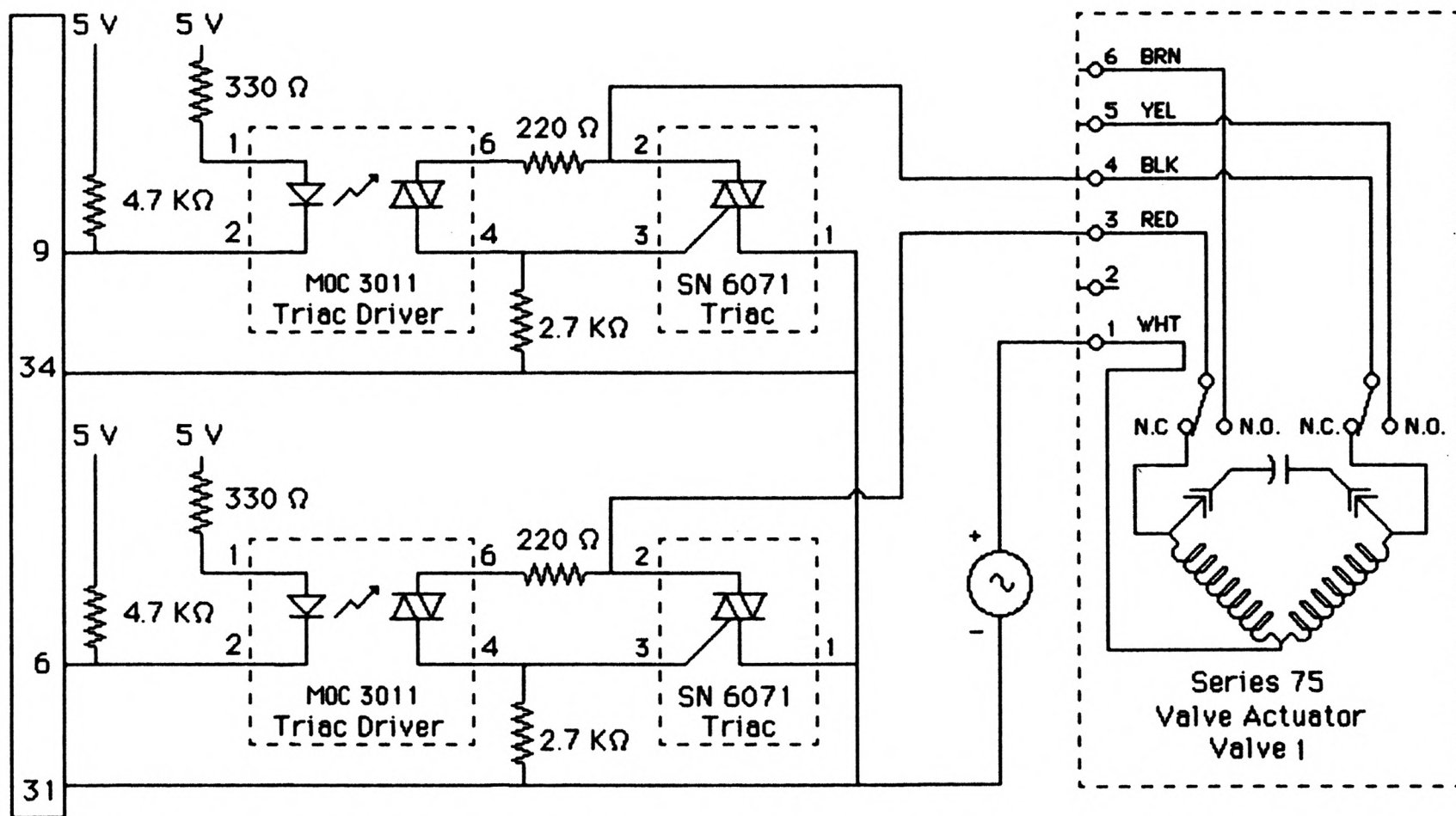


Figure 5.3
Optic Isolation Layout
(Base Board)



Connector P1

Figure 5.4
Solid State Switching Circuit
Flow Control Valve 1

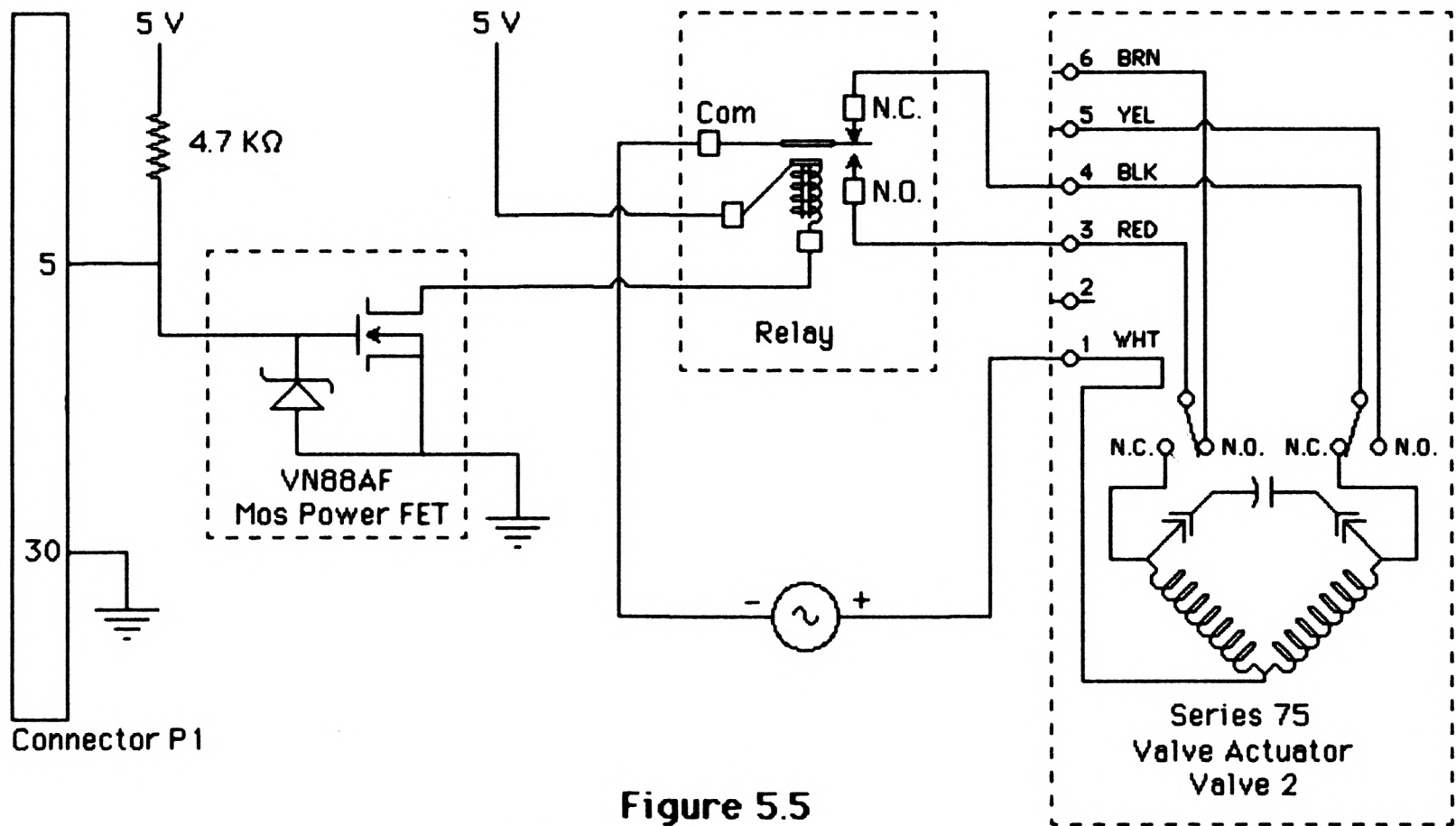
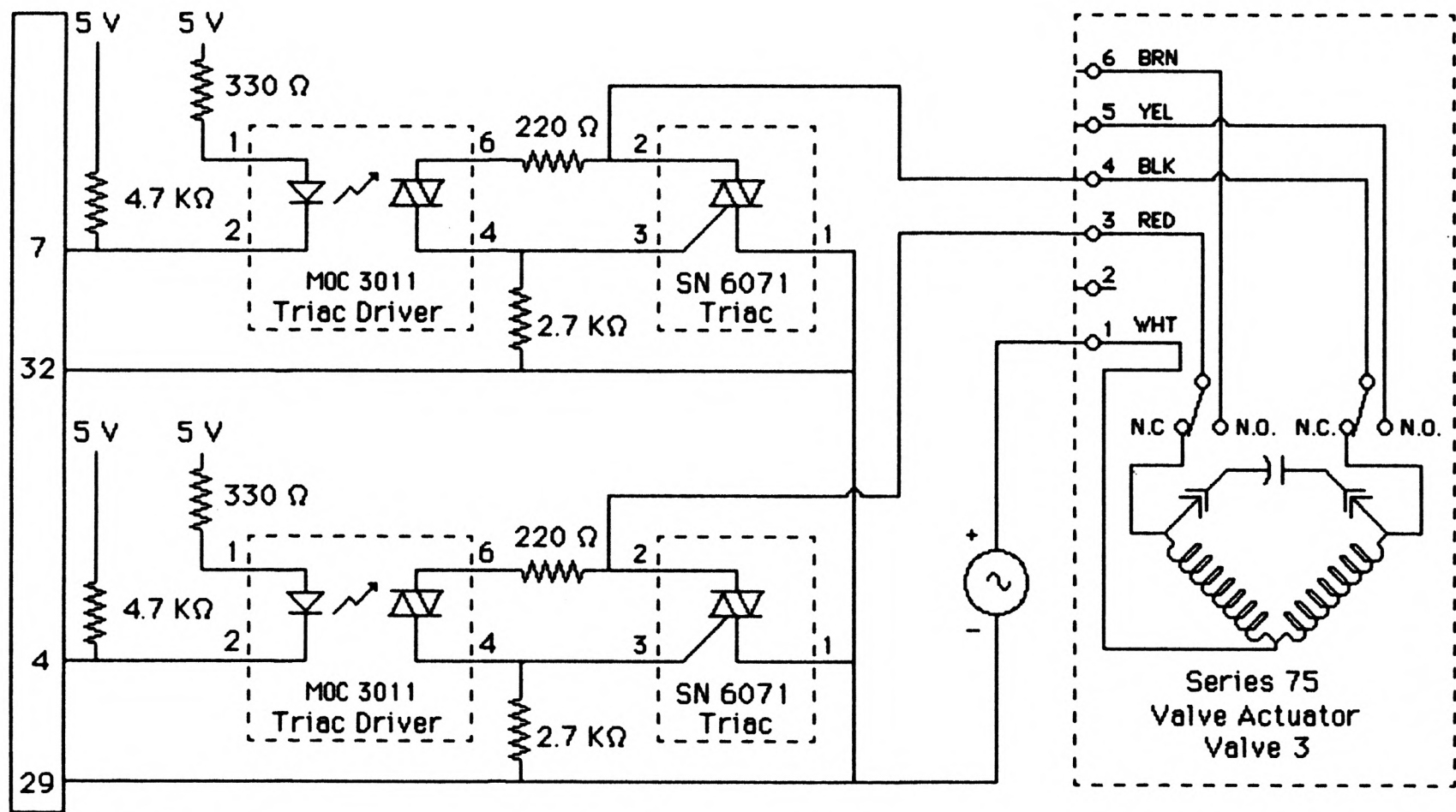


Figure 5.5
Switching Circuitry
Control Flow Valve 2



Connector P2

Figure 5.6
Solid State Switching Circuit
Flow Control Valve 3

state design which uses triacs to switch the AC power through the individual windings. The valve actuators have built in limit switches which remove the AC power from the windings when the actuators are either full on or full off. Since the valves will be located in a thermally guarded system, the power must be completely removed from the windings once the flow rate has been set. Triacs were chosen for valves 1 and 3 because the response of a triac is much faster than a relay and we can pulse the AC motors without having to worry about contact bounce on a relay.

The switching circuitry receives its signals from one optically isolated parallel port which is part of the Base board which is located in the Techmar Expansion Chassis. The valves are to be controlled one at a time by controlling the individual bits of parallel port A. Valve 2 will be controlled with a relay because we will not have to modulate the position of this valve. The relay chosen for valve 2 is a 5V double pole single throw relay. The operation of the valves will be controlled by setting bits of the parallel port. The operation of the valves are shown in Table 3 below. Note the variable *e* is set to either a 1 or 0 which corresponds to valve 2 being in the calibration heater position or the heat exchanger position. The goal of the circuitry was to control all 3 valves with only one output port. The variable *e* keeps the first bit set or reset depending on the position of valve 2. Figure 5.6 is a wiring schematic for valve 3 and Figure 5.3 shows the opto isolation between the Base I/O board and the switching circuitry. A logical 1 on bit A0 switches the FET which in turn energizes the relay coil. The actuator will operate the 3 way valve to either the heat exchanger position or the calibration heater position. This valve was not used in this test set up, but the circuitry has been developed and tested.

| Port A | | | | | | | | DECIMAL | FUNCTION |
|--------|----|----|----|----|----|----|----|----------|-----------------|
| A7 | A6 | A5 | A4 | A3 | A2 | A1 | A0 | | |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | e | 255-e | All Valves Stop |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 255, e=1 | Open Valve 2 |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 254, e=0 | Close Valve 2 |
| 1 | 1 | 1 | 1 | 1 | 0 | 1 | e | 251-e | Open Valve 3 |
| 1 | 1 | 1 | 1 | 0 | 1 | 1 | e | 247-e | Close Valve 3 |
| 1 | 1 | 1 | 0 | 1 | 1 | 1 | e | 239-e | Open Valve 1 |
| 1 | 1 | 0 | 1 | 1 | 1 | 1 | e | 223-e | Close Valve 1 |

Table 3

Analog to Digital Converter and Pin Connections

The Lab Master board has a 12 bit analog to digital converter with programmable gain. The analog input signals are conditioned into digital signals at the daughter board. Two analog signals were required for input into the control program. One of the signals was for the temperature difference transducer and the other for the control heater power monitor output signal. A 1 K ohm resistor placed across the power monitor, see Figure 2.2 produces a 0 to 10 volt signal. When the analog input ports are read a programmable gain of 1 is used in the control program. The gain for the temperature difference transducer is variable and is set at either 500 or 100 depending on the level of the output signal. These analog signals are brought to the data translation screw terminal input board (see Controls Project File, reference 2). The signals are filtered at the data translation interface board and then are sent to the lab master daughter board via connector P1D. (see Control Product File). The analog inputs are configured in the true differential mode. See page 39 of the Lab Master manual for jumper locations (reference 18). The connections are shown in Table 4.

| Terminal Strip # | Channel # True Differential | Connector P1D Pin # | Control Signals Connected |
|---------------------|-----------------------------------|---------------------------|---|
| T39 | 0+ | 20 | Temperature Difference sensor |
| T37 | 0- | 19 | Temperature Difference sensor |
| T35 | 1+ | 18 | Common |
| T33 | 1- | 17 | Common |
| T31 | 2+ | 16 | Common |
| T29 | 2- | 15 | Common |
| T27 | 3+ | 14 | Common |
| T25 | 3- | 13 | Common |
| T23 | 4+ | 12 | Power monitor Analog out (+) |
| T21 | 4- | 11 | Power monitor Analog out (-), gnd |
| T19 | 5+ | 10 | Common |
| T17 | 5- | 9 | Common |
| T15 | 6+ | 8 | Common |
| T13 | 6- | 7 | Common |
| T11 | 7+ | 6 | Common |
| T9 | 7- | 5 | Common |
| Comm | gnd | 1-4, 21-40 | Note the common lines between The 2 barrier strips are not connected by the etching pattern. Install a jumper between Com7 and Com8 to connect the two. |

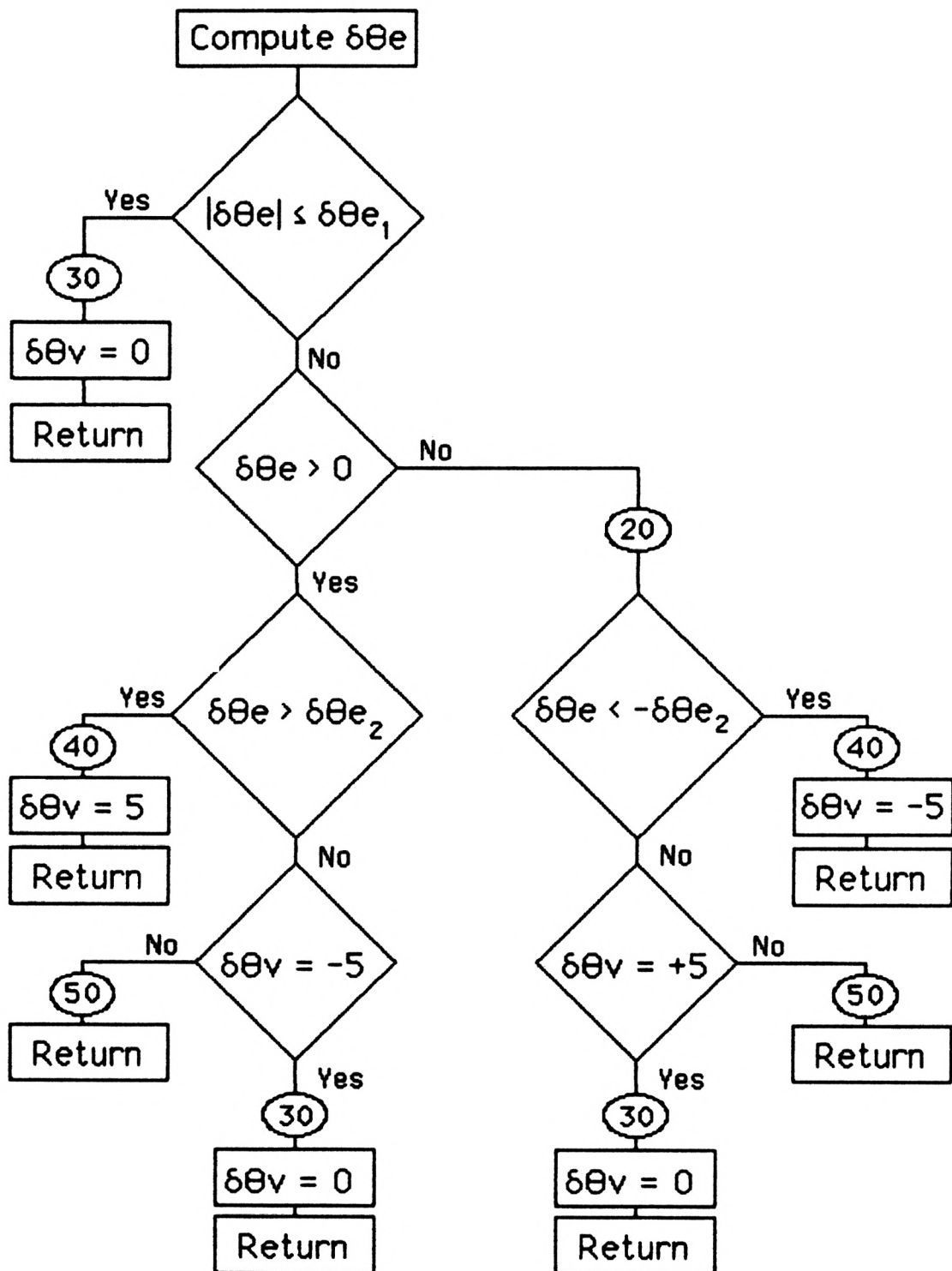
Table 4 Analog Input Board Connections

| | Pin # | Fuction | I/O Interface Label |
|----------------|--------|------------------------|------------------------|
| Connector J4: | 1 | DAC 0 | Dac 0 |
| Digital to | 2 | DAC 1 | Dac 1 |
| Analog conv | 3-10 | ground | gnd |
| Connector J2: | 21-40 | ground | gnd |
| Timer/Counters | 1,2 | +5 volts | +5 |
| | 16 | Done | Done |
| | 3 | External Start Conv | Ex St. Conv |
| | 4 | Out 5 | O5 |
| | 9 | Gate 5 | G5 |
| | 14 | Source 5 | S5 |
| | 5 | Out 4 | O4 |
| | 10 | Gate 4 | G4 |
| | 15 | Source 4 | S4 |
| | 6 | Out 3 | O3 |
| | 11 | Gate 3 | G3 |
| | 17 | Source 3 | S3 |
| | 7 | Out 2 | O2 |
| | 12 | Gate 2 | G2 |
| | 18 | Source 2 | S2 |
| | 8 | Out 1 | O1 |
| | 13 | Gate1 | G1 |
| | 19 | Source 1 | S1 |
| | 20 | Fout | F0 |
| Connector J3: | 1 | PA7 | A7 |
| Parallel I/O | 14 | PA6 | A6 |
| | 2 | PA5 | A5 |
| | 15 | PA4 | A4 |
| | 3 | PA3 | A3 |
| | 16 | PA2 | A2 |
| | 4 | PA1 | A1 |
| | 17 | PA0 | A0 |
| | 5 | PC7 | C7 |
| | 18 | PC6 | C6 |
| | 6 | PC5 | C5 |
| | 19 | PC4 | C4 |
| | 7 | PC3 | C3 |
| | 20 | PC2 | C2 |
| | 8 | PC1 | C1 |
| | 21 | PC0 | C0 |
| | 9 | PB7 | B7 |
| | 22 | PB6 | B6 |
| | 10 | PB5 | B5 |
| | 23 | PB4 | B4 |
| | 11 | PB3 | B3 |
| | 24 | PB2 | B2 |
| | 12 | PB1 | B1 |
| | 25 | PB0 | B0 |
| | 13, 26 | ground | gnd |

Table 5. Lab Master I/O Interface Board Connectors

APPENDIX B

NONLINEAR FUNCTION FLOWCHART



Flow Chart Nonlinear – $\delta\theta v$ Controller

$\delta\theta_v$ Program Segment

```

IF [  $\delta\theta_e$  ]  $\leq \delta\theta_{e1}$  then goto 30

IF  $\delta\theta_e < 0$  then goto 20

IF  $\delta\theta_e > \delta\theta_{e2}$  then goto 40

IF  $\delta\theta_v < > -5$  then goto 50

Goto 30

20 IF  $\delta\theta_e < -\delta\theta_2$  then goto 45

IF  $\delta\theta_v < > -5$  then goto 50

Goto 30

30  $\delta\theta_v = 0$ 

GOTO 50

40  $\delta\theta_v = 5$ 

Goto 50

45  $\delta\theta_v = -5$ 

Goto 50

50 RETURN

```

APPENDIX C

PROGRAM LISTINGS

```

10 ! *****PROGRAM "SIMASH"*****
20 ! THIS IS A SIMULATION OF THE CONTROL HEATER WHICH USES A 0 TO 120 V *
30 ! MOTOR DRIVEN VARIAC AND A 0 TO .75 MOTOR DRIVEN RHEOSTAT *
40 ! TO CONTROL THE POWER TO THE HEATING ELEMENT OF H1. *
50 ! *****
51 S=1 !DEFAULT VALUE OF TEMPERATURE SCALE RANGE
60 PRINT "INPUT TEMPERATURE SCALE RANGE + or - S"
61 PRINT "S is in degrees farenheit Default value is 1 F"
62 PRINT
70 INPUT S
110 Kp=3 !PROPORTIONAL GAIN
120 Ki=.3 !INTEGRAL GAIN
130 Kd=.01 !DERIVATIVE GAIN
131 PRINT "INPUT Kp,Ki,Kd DEFAULT XS Kp=3 Ki=.3 Kd=.01"
140 INPUT Kp,Ki,Kd
141 L=1 !INDICATES TOP SECTION OF GRAPH
142 DEG !USED ONLY IN LDIR COMMAND
150 PLOTTER IS 13,"GRAPHICS" !SET UP GRAPHICS
160 GRAPHICS
180 LOCATE 20,120,0,100
190 SCALE 0,600,0,1.515*S !UNIFORM SCALE
200 CLIP 0,600,0,1*S !GIVES TOP MARGIN
210 AXES 60,.01*S,0,-.1*S,1,10 !X AXIS NOT SHOWN
220 MOVE 0,0
230 DRAW 600,0
240 LDIR 90 !90 DEGREE ROTATION OF LABLES
250 MOVE -55,0
260 LABEL "<degree farenheit>"
270 LONG 4 !RELATIVE LOWER CENTER POSITION ON LABLES
280 FOR I=0 TO 10 STEP 2 !LABEL TOP OF TEMPERATURE AXIS
290 MOVE -10,I/10*S
300 LABEL I/10*S
310 NEXT I
320 GOSUB 800 !GET RESPONSE PLOT ON TOP OF FIGURE
330 DUMP GRAPHICS
340 GCLEAR
350 L=0 !INDICATES BOTTOM OF FIGURE FOR SUBROUTINE
360 LDIR 0 !0 DEGREE ROTATION OF LABLES
370 LONG 1 !NORMAL RELATIVE POSITION OF LABLES
380 LOCATE 20,120,34.4,100 !DEFINE THE CRT BOUNDS FOR PLOTTING
390 SCALE 0,600,0,.995*S !MAKE THE SCALING FOR THE GRAPH 10 MINUTES
400 AXES 60,.01*S,0,0,1,10 !SET 1 MINUTE TICK MARKS AND .1 F TICKS
430 MOVE 270,.3*S !LABEL THE GRAPH
440 LABEL "Kp=";Kp !LABEL Kp
450 MOVE 270,.2*S
460 LABEL "Ki=";Ki !LABEL Ki
470 MOVE 270,.1*S
480 LABEL "Kd=";Kd !LABEL Kd
490 MOVE 210,-.1*S
500 LABEL "TIME (minutes)" !LABEL BOTTOM AXIS
510 LONG 4 !RELATIVE BOTTOM CENTER POSITION OF LABEL
520 FOR I=0 TO 10 !LOOP TO LABEL SCALE ON TIME AXIS
530 MOVE I*60,-.05*S
540 LABEL I
550 NEXT I
560 MOVE 265,-.3*S

```

Program developed on
Hewlett Packard 9845B
Computer System

```

570 LABEL "STEP RESPONSE OF TEMPERATURE DIFFERENCE" !LABEL FIGURE TITLE
580 MOVE 265,-.36*S
590 LABEL "FIGURE" !LABEL FIGURE NUMBER
600 LDIR 90 !90 DEGREE ROTATION OF LABELS
610 MOVE -55,.67*S
620 LABEL "TEMPERATURE DIFFERENCE " !LABEL TEMPERATURE AXIS
630 FOR I=-10 TO 0 STEP 2 !LOOP TO LABEL SCALING OF BOTTOM TEMP AXIS
640 MOVE -10,(I+10)/10*S
650 LABEL I/10*S
660 NEXT I
670 LDIR 0 !0 DEGREE ROTATION OF LABELS
680 LONG 1
690 MOVE 420,.3*S
700 LABEL "T =7 sec" ! LABEL T
710 MOVE 420,.25*S
720 LABEL "Tau =16 sec" ! LABEL Tau
730 MOVE 420,.2*S
740 LABEL "Flow =.46 gpm" ! LABEL Flow
750 MOVE 420,.15*S
760 LABEL "Th =0 F" ! LABEL Th
770 MOVE 420,.1*S
771 LABEL "Tsys =10 F" ! LABEL Tsys
780 GOSUB 800 !GET RESPONSE PLOT FOR BOTTOM OF FIGURE
781 DUMP GRAPHICS
790 STOP
800 ! *****INITIALIZATION*****
810 MOVE 0,0
820 DIM P(7) !16 REPRESENTS TIME DELAY OF HEATER
830 Th=0 !DELTA TEMP ACROSS THE HEATER IS ZERO INITIALLY
840 K3=Kp !VARIABLE USED IN LINE 540 FOR CALC. Ps (PID)
850 K1=Kd/K3 !VARIABLE USED FOR PID CONTROLLER
860 K2=Ki/K3 !VARIABLE USED FOR PID CONTROLLER
870 R1=15.4 !RL=RESISTANCE OF THE CONTROL HEATER
880 Cv=120/230 !CONSTANT FOR THE VARIAC (120 VOLTS)/(230 WINDINGS)
890 Cr=.75/41 !CONSTANT FOR THE RHEOSTAT (.75 OHMS)/(41 WINDINGS)
900 Tr=0 !THETA OF THE RHEOSTAT IS CENTERED
910 H=1 !SAMPLING RATE OF THE CONTROL SYSTEM IS 1 SECOND
920 Kr=-1/(1.222*H) ! (WINDINGS OF RHEO)/(WATT*SEC) 1.933...NOT LINEAR
930 Ts=0 ! THETA OF RHEOSTAT SET (WINDINGS)
940 Dv=0 !DELTA OF VARIAC=0 (WINDINGS)/(SEC)
950 Dr=0 !DELTA OF RHEOSTAT=0 (WINDINGS)/(SEC)
960 E2=1 !INITIAL VALUE OF RHEOSTAT CONTROLLER
970 E3=15 !MAXIMUM VALUE OF RHEOSTAT CONTROLLER
980 Ev=5 !INITIAL VALUE OF VARIAC INCREMENT IF RHEO OUT OF BOUNDS
990 Tsys=10 !DELTA T ACROSS SYSTEM HEAT EXCHANGER IS 8 DEG. F
1000 T=0 !REAL TIME STARTS AT ZERO
1010 A=H/16 !THE 35 IS THE TIME CONSTANT OF THE CONTROL HEATER
1020 X=(Th-Tsys)*15.78 !CALCULATE X IN MILLIVOLTS...(15.78 MV)/(DEG F)
1030 E1=-X !INITIAL VALUE OF THE PREVIOUS DERIV. TERM
1040 Th1=Th !INITIAL VALUE OF THE PREVIOUS CONTROL HEATER DELTA TEMP
1050 K6=1*8.323*.46*60*.293!WATT/F=(BTU/# F)(#/GAL)(GAL/MIN)(MIN/HR)(WATT.HR/BTU
1060 V1=Th*K6/K2/K3 ! SET THE INITIAL INTEGRAL TERM (WATTS)
1070 Tv=SQR(Th*K6*(R1+Cr*Tr)^2/(R1*Cv^2)) !CALC. INITIAL THETA V
1080 Tv=Tv-115
1090 FOR I=0 TO 7 !INITIALIZE THE TIME DELAY ARRAY FOR THE CONTROL HEATER
1100 P(I)=Th*K6 ! WATTS
1110 NEXT I

```

```

1240 ! *****
1250 !
1260 !
1270 ! *****BEGIN COMPUTATION*****
1280 FOR K=1 TO 600/H ! 10 MINUTE SIMULATION WITH H=1
1290 T=T+H ! INCREMENT THE TIME
1300 E=-X ! DERIVATIVE DELTA TERM
1310 V=V1+H*E ! CALCULATE THE INTEGRAL TERM
1320 Ps=K3*(E+K2*V+K1*(E-E1)/H) ! POWER SET (****PID****)
1330 Dr=Kr*(Ps-P(0)) ! CALCULATE THETA R DOT (WINDING)/SEC
1340 Tr=Tr+Dr*H ! INTEGRATE THETA R DOT (WINDINGS)
1350 Tr=INT(Tr)
1360 IF Tr<-18 THEN Tr=-18 ! LOWER BOUNDS ON RHEOSTAT
1370 IF Tr>18 THEN Tr=18 ! UPPER BOUNDS ON RHEOSTAT
1380 ! *****CONTROL THE VARIAC*****
1390 De=Ts-Tr
1400 IF ABS(X)<5 THEN Ev=1/H ! HAVE RHEOSTAT DO MOST OF THE CONTROL
1410 IF ABS(X)>5 THEN Ev=5/H ! HAVE VARIAC DO MOST OF THE CONTROL
1420 IF ABS(De)<=E2 THEN GOTO 1730
1430 IF De<0 THEN GOTO 1700
1440 IF De>E3 THEN GOTO 1750
1450 IF Du<>-Ev THEN GOTO 1790
1460 GOTO 1730
1470 Tv=Tv+H*Dv ! INTEGRATE THETA V DOT
1480 Tv=INT(Tv)
1490 IF Tv<-112 THEN Tv=-112 ! SET BOUNDS ON THETA OF VARIAC
1500 IF Tv>112 THEN Tv=112
1510 P(0)=R1*Cv^2*(Tv+115)^2/(R1+Cr*(Tr+20))^2 ! CALCULATE MEASURED POWER INPUT
1520 Th=(1-A)*Th1+A*P(7)/K6 ! CALCULATE NEW Th (FINITE DIFFERENCE USED)
1530 X=(Th-Tsys)*15.78 ! CALCULATE NEW DELTA T SIGNAL IN MILLIVOLTS
1540 PRINT T,Tv,Tr,X ! PRINT VARIABLES
1550 M=X/15.78 ! CONVERTS FROM MILIVOLTS TO DEGREES F
1560 IF L=0 THEN M=M+S ! SHIFTS THE ZERO FOR BOTTOM BY SCALE FACTOR
1570 PLOT T,M ! PLOT TIME ON THE HORIZ AXES AND MV ON THE VERTICAL
1580 E1=E ! E1=THE NEG OF THE PREVIOUS X
1590 Th1=Th ! X1=CURRENT VALUE OF X
1600 V1=V ! INTEGRAL TERM = THE CURRENT INTEGRAL TERM
1610 FOR I=0 TO 6 ! SHIFT THE ARRAY FOR TIME DELAY
1620 P(7-I)=P(6-I)
1630 NEXT I
1640 NEXT K ! CALCULATE X FOR THE NEXT TIME INCREMENT
1650 RETURN
1660 ! *****END COMPUTATIONS*****
1670 !
1680 !
1690 ! *****SUBROUTINES*****
1700 IF De<-E3 THEN GOTO 1770 ! DELTA THETA V SUBROUTINES SEE FLOW CHART
1710 IF Du<>-Ev THEN GOTO 1790
1720 GOTO 1730
1730 Du=0
1740 GOTO 1470
1750 Dv=Ev
1760 GOTO 1470
1770 Dv=-Ev
1780 GOTO 1470
1790 GOTO 1470
1800 END

```


Program "ASHRAE14.BAS", pg. 1 of 8

Program Developed using IBM XT
Computer System.

```

1  TM=100
2  GOSUB 9000
5   ON ERROR GOTO 0
6  F=0
10 E=1
20 CLS:KEY OFF:E$=""
25 OUT 532,&H80      'set up port a base board as output
26 OUT 535,255-E     'stop all valves
30 PRINT"ENTER ONE OF THE NUMBERS BELOW"
40 PRINT:PRINT:PRINT"1)CONTROL VALVE 1.....CALIBRATION HEATER"
50 PRINT"2)CONTROL VALVE 2.....3 WAY VALVE"
60 PRINT"3)CONTROL VALVE 3.....CONTROL HEATER (ADJUST TO .7 GPM)"
70 PRINT"4)GO ON TO THE CONTROL SEGMENT"
80 PRINT"5)ABORT"
90 INPUT D
100 IF D=1 THEN GOTO 160
110 IF D=2 THEN GOTO 170
120 IF D=3 THEN GOTO 180
130 IF D=4 THEN GOTO 2400
140 IF D=5 THEN GOTO 670
150 GOTO 20
160 F$="VALVE 1.....CALIBRATION HEATER" : GOTO 190
170 F$="VALVE 2.....3 WAY VALVE" : ZZ=255 : GOTO 190
180 F$="VALVE 3.....CONTROL HEATER"
190 KEY 1,"OPEN" :KEY 2,"PULSO" :KEY 3,"CLOSE" :KEY 4,"PULSC" :KEY 5,"RESTRT"
195 KEY 6,"ABORT" : KEY 7,"" :KEY 8,"" :KEY 9,"" :KEY 10,""
200 CLS: KEY ON
205 F=0
210 PRINT F$; "    VALVE 1 PULSE=";P1 ;"    VALVE 3 PULSE=";P3
215 PRINT E$
220 PRINT:PRINT:PRINT:PRINT"TO CONTROL A VALVE SELECT A SHIFTED FUNCTION KEY"
225 'KEY(1) ON : KEY(2) ON : KEY(3) ON : KEY(4) ON : KEY(5) ON : KEY(6) ON
230 A$=INKEY$ :IF A$="" THEN 230
235 IF A$=CHR$(0)+CHR$(84) THEN F=1
240 IF A$=CHR$(0)+CHR$(85) THEN F=2
250 IF A$=CHR$(0)+CHR$(86) THEN F=3
260 IF A$=CHR$(0)+CHR$(87) THEN F=4
270 IF A$=CHR$(0)+CHR$(88) THEN F=5
280 IF A$=CHR$(0)+CHR$(89) THEN F=6
300 IF ((D=1) AND (F=1)) OR ((D=1) AND (F=2)) THEN ZZ=239
320 IF ((D=1) AND (F=3)) OR ((D=1) AND (F=4)) THEN ZZ=223
340 IF (D=2) AND (F=1) THEN E=0
360 IF (D=2) AND (F=3) THEN E=1
370 IF ((D=2) AND (F=2)) OR ((D=2) AND (F=4)) THEN GOTO 200
380 IF ((D=3) AND (F=1)) OR ((D=3) AND (F=2)) THEN ZZ=251

```

Program "ASHRAE14.BAS" page 2 of 8

```

400 IF ((D=3) AND (F=3)) OR ((D=3) AND (F=4)) THEN ZZ=247
420 IF (F=1) OR (F=3) THEN GOTO 500 'OPEN OR CLOSE ROUTINE
430 IF (F=2) OR (F=4) THEN GOTO 600 'PULSING ROUTINE
440 IF (F=5) THEN GOTO 20 'RESTART THE SEQUENCE
450 IF (F=6) THEN GOTO 670 'ABORT ROUTINE
460 GOTO 225
500 ' FULL OPEN AND FULL CLOSE ROUTINE
520 IF INP(1820)=0 THEN 520
530 OUT 535,(ZZ-E) 'OUTPUT TO THE PARALLEL PORT A...BASE BOARD
540 FOR N=0 TO 6
550 IF INP(1820)=0 THEN 550
560 PRINT TIME$
570 NEXT N
580 OUT 535,255-E 'STOP ALL VALVES....REMOVES ALL POWER TO VALVES
585 IF F=3 THEN E$="VALVE CLOSED"
586 IF F=1 THEN E$="VALVE OPENED"
587 IF D=1 THEN P1=0
588 IF D=3 THEN P3=0
589 F=0
590 GOTO 200
595 PRINT"error":STOP
600 '
620 IF INP(1820)=0 THEN 620
630 OUT 535,(ZZ-E)
635 ' FOR N= 0 TO 1
640 IF INP(1820)=0 THEN 640
645 PRINT TIME$
646 ' NEXT N
650 OUT 535,255-E
651 IF (D=1) AND (F=2) THEN P1=P1+1
652 IF (D=1) AND (F=4) THEN P1=P1-1
653 IF (D=3) AND (F=2) THEN P3=P3+1
654 IF (D=3) AND (F=4) THEN P3=P3-1
655 E$="VALVE PULSED"
656 F=0
660 GOTO 200
670 'ABORT ROUTINE
675 OUT 535,255-E :CLS
680 PRINT" UNPLUG THE VALVES !!!!!!!!!!!!!!"
690 STOP
2400 '*****
2410 ' STEPPER INITIALIZE
2420 '*****
2430 CLS
2520 PRINT"TO INITIALIZE THE STEPPING MOTORS FIRST BE SURE THAT THE POWER"
2530 PRINT"TO THE VARIAC AND RHEOSTAT HAS BEEN REMOVED";
2540 PRINT"NOW PLEASE POSITION THE VARIAC AND RHEOSTAT AT TOP END"
2550 PRINT"NOW PLEASE PLUG IN THE POWER FOR THE CONTROL HEATER"
2555 PRINT "PRESS RETURN AFTER YOU HAVE DONE THIS";: INPUT N
2560 DIM C$(20) ' Character string array holds command statements

```

Program "ASHRAE14.BAS", page 3 of 8

```

2570 DIM A(20)          ' Numerical array holds ASCII values of commands
2580 XS=768             ' X controller and status address
2590 YS=769             ' Y controller and status address
2600 DAR=770            ' Data bus address
2610 IX=771             ' X interrupt address
2620 IY=772             ' Y interrupt address
2630 DS=773             ' X and Y dual status address
2640 OUT XS,0           ' Reset X controller . . . Bit 4=0
2650 OUT YS,0           ' Reset Y controller . . . Bit 4=0
2660 OUT XS,190         ' Set X controller desired initial conditions
2670 OUT YS,190         ' Set Y controller desired initial conditions
2680 C$(1)="H"          ' Halfstep command for variac only
2690 C$(2)="N 178"      ' Center position for motor total is 356 halfsteps
2700 C$(3)="+"          ' Set rate
2710 C$(4)="R 200"      ' Set slope
2720 C$(5)="S 30"       ' Set factor....should be in this order
2730 C$(6)="F 1"        ' Athome...Makes the current position of stepper 0
2740 C$(7)="A"          ' Set direction of stepping
2750 C$(8)="E"          ' Enter the program mode
2760 C$(9)="G"          ' Go....execute any N command with appropriate sign
2770 C$(10)="O"         ' CY512 program end
2780 C$(11)="Q"         ' Get out of program mode and get into control mode
2790 C$(12)="D"         '
2800 M1=12              ' Number of command statements
2810 SR=XS              ' Set X as default controller
2820 OUT IX,0           ' Clears interrupt address (address not used)
2830 OUT IY,0           ' Clears interrupt address (address not used)
2840 GOSUB 8000          ' Subroutine will initialize variac controller
2850 C$(1)="H"          '
2860 C$(2)="N 311"      ' Center position of rehostat motor
2870 SR=YS              ' Sets rheostat address
2880 GOSUB 8000          ' Subroutine will initialize rheostat controller
2890 C$(3)="D"          ' Doitnow command used in actual stepping
2900 M1=3               ' Number of commands in actual stepping
2910 TV1=0 :TR1=18
3000 'WAITING LOOP FOR VARIAC AND RHEOSTAT TO GET TO THE CENTER
3010 TM=100
3020 GOSUB 9000
3030 N=0
3040 FOR N=0 TO 2
3050 IF INP(1820)=0 THEN 3050
3060 NEXT N
4000 '*****
4010 ' INITIALIZE THE A/D CONVERTER (4000)
4020 '*****
4030 REM ANALOG          USE THE AUTO-INCREMENT FEATURE TO PERFORM ANALOG TO DIGITAL
4040 REM 6/22            CONVERSIONS OF CHANNELS 0 TO 7. THE INPUT RANGE IS PROGRAM
4050 REM                 ABLE AT START UP. THE BOARD MUST BE IN THE I/O MAPPED
4060 REM                 MODE. THE SWITCHES ON THE DAUGHTER BOARD SHOULD BE SET TO 7
4070 REM                 (1-3 ON, 4-8 OFF)

```

Program "ASHRAE14.BAS" page 4 of 8

```

4080 DIM B(8)
4085 OUT 831,&H80      ' O-SCOPE TIMING OUTPUT PORT INITIALIZATION
4090 CLS
4100 REM   STARTING ADDRESS OF BOARD IS 1808
4110 ADDRESS=1808
4120 REM DO A CONVERSION WITH THE CHANNEL EQUAL TO 255 SO CHANNEL 0 WILL BE THE
4130 REM FIRST CHANNEL TO BE CONVERTED IN THE AUTO-INCREMENT LOOP. (IN THE
4140 REM AUTO-INCREMENT MODE THE CHANNEL IS INCREMENTED BEFORE EACH CONVERSION)
4150 OUT ADDRESS + 4,128
4160 OUT ADDRESS +5, 255
4170 OUT ADDRESS +6, 0
4180 REM WAIT INTIL BIT 7 OF STATUS BYTE EQUALS 1 SIGNALING DONE CONVERTING.
4190 IF INP(ADDRESS + 4)<128 THEN 4190
4200 REM RESET DONE BIT BY READING HIGH BYTE.
4210 X=INP(ADDRESS +6)
4230 '*****
4235 '           INITIALIZE TIMER COUNTER 1
4240 '*****
4250 TM=100
4252 GOSUB 9000
4265 '*****
4266 '           INITIALIZE CONTROL VARIABLES
4267 '*****
4270 X=0           'assumes we start with a temp difference of 0
4275 TIME=0
4280 KP= 3           'PROPORTIONAL GAIN SET
4290 KI=.3           'INTEGRAL GAIN SET
4295 KD=.01
4300 K3=KP
4310 K1=KD/K3
4320 K2=KI/K3
4325 K7=1000/10000 ' 1000 W/19.4 MILLIVOLTS      19.4 OHM RESISTOR AT PWRMON
4330 R1=15.4
4332 CV=120/356     '120V/356 STEPS...HALF STEP MODE
4334 CR=.75/41
4336 TR=18
4340 H=1
4345 TS=0
4350 KR=-1/(1.933*H)
4360 DV=0
4370 DR=0
4380 E2=5
4390 E3=15
4400 EV=5
4410 E1=-X
4430 K6=1*8.323*.46*60*.293
4440 V1=X/15.78*K6/K2/K3 'will be zero if x=0
4500 '*****
4510 '           Setup speed disk d as data storage device
4520 '*****

```

Program "ASHRAE14.BAS" page 5 of 8

```

4530 PRINT"input file name for data storage"
4540 INPUT P$
4550 IF LEN(P$)<=11 THEN GOTO 4580
4560 PRINT"Filename length must not exceed 11 characters"
4570 GOTO 4530
4580 OPEN "d:"+P$ FOR OUTPUT AS #1
5000 '*****
5005 '                                CONTROL SEGMENT
5006 '*****
5007 REM OUTPUT THE STARTING CHANNEL IN THE SEQUENCE= 0
5008 OUT ADDRESS+5,0
5009 OUT 829,3
5010 IF ABS(B(0))<= 19 THEN GAIN=500
5011 IF ABS(B(0))>19 THEN GAIN=100
5012 X=0
5013 FOR M=1 TO 10                'read the delta t sensor 10 times and
5014 GOSUB 7021                    'take the average
5015 X=X+B(0)
5016 NEXT M
5017 OUT 829,1
5018 X=X/10
5019 PRINT #1,X
5020 G$=INKEY$
5021 IF G$=CHR$(3) THEN GOTO 9300
5025 GAIN=1                        'change the gain to read the power monitor
5026 GOSUB 7021
5030 E=-X                          'DERIVATIVE DELTA TERM
5040 V=V1+H*E                      'CALCULATE THE INTEGRAL TERM
5045 V1=V
5050 PS=K3*(E+K2*V+K1*(E-E1)/H)    'POWER SET (****PID****)
5060 PO=K7*-B(4)                   'POWER FROM THE CONTROL HEATER WATT METER
5070 DR=KR*(PS-PO)                 'CALCULATE THETA R DOT (WINDINGS)/(SEC)
5080 TR=TR+DR*H                    'CALCULATE THETA R (WINDINGS)
5085 TR=INT(TR)
5090 IF TR<-18 THEN TR=-18          'THETA OF THE RHEOSTAT IS DISCRETIZED
5100 IF TR>18 THEN TR=18
5110 DE=TS-TR                      'THETA SET-THETA RHEOSTAT
5120 IF ABS(X)<5 THEN EV=1/H
5130 IF ABS(X)>=5 THEN EV=5/H
5140 IF ABS(DE)<=E2 THEN GOTO 5890
5150 IF DE<0 THEN GOTO 5860
5160 IF DE>E3 THEN GOTO 5910
5170 IF DV<>-EV THEN GOTO 5950
5180 GOTO 5890
5190 TV=TV+H*DV
5210 IF TV<-175 THEN TV=-175
5220 IF TV>175 THEN TV=175
5230 '*****
5240 '                                STEPPER MOTOR CONTROL SEGMENT
5245 '*****

```

Program "ASHRAE14.BAS" page 6 of 8

```

5250 IF TV-TV1=0 THEN GOTO 5300 ' DV          test for change in variac
5260 SR=768                      ' SR          variac address
5270 D=CINT((TV-TV1)*H*1)        ' D,DV,H    calculate relative step variac
5280 TV1=TV
5290 GOTO 5340                    '          send step routine to controller
5300 IF TR-TR1=0 THEN GOTO 5530 ' DR*DONE**test for change in rheostat
5310 SR=769                      ' SR          rheostat address
5320 D= INT((TR-TR1)*H*8 )       ' D,DR,H    calculate relative step rehostat
5330 TR1=TR
5340 IF D>=0 THEN C$(1)="+" ELSE C$(1)="-" 'D,B$ stepping direction
5350 C$(2)="N"+STR$(ABS(D))      ' B$,D      step value must be positive
5360 M1=3                        ' M1
5370 GOSUB 8000                  '          send controler instructions
5380 IF SR=768 THEN GOTO 5300
5530 PRINT TIME,PO,X
5600 OUT 829,0
5603 IF INP(1820) = 0 THEN 5603   'CHECK BIT 0 OF PORT A IF 0 THEN 1 SEC
5605 OUT 829,1                   ' page 22 lab tender 4B
5610 '                           'HAS GONE BY....
5615 TIME=TIME+1
5620 GOTO 5009                   'GO AND READ IN NEW VALUES
5840 '*****
5850 '          DELTA THETA V SUBROUTINES
5855 '*****
5860 IF DE<=-E3 THEN GOTO 5930
5870 IF DV<>=-EV THEN GOTO 5950
5880 GOTO 5890
5890 DV=0
5900 GOTO 5190
5910 DV=EV
5920 GOTO 5190
5930 DV=-EV
5940 GOTO 5190
5950 GOTO 5190
7000 '*****
7010 '          BEGIN ANALOG TO DIGITAL CONVERSIONS
7020 '*****
7021 IF GAIN=1 THEN OUT ADDRESS+4,0
7022 IF GAIN=10 THEN OUT ADDRESS+4,1
7023 IF GAIN=100 THEN OUT ADDRESS+4,2
7024 IF GAIN=500 THEN OUT ADDRESS+4,3
7025 K5=20/(4096*GAIN)
7030 REM DO 16 CONVERSIONS AND SAVE THE VOLTAGES.
7040 FOR Y= 0 TO 7
7050 REM START A CONVERSION.
7060 OUT ADDRESS + 6, 0
7070 REM WAIT UNTIL BIT 7 OF STATUS BYTE EQUALS 1 SIGNALING DONE CONVERTING
7080 REM READ IN THE DATA
7090 LOW=INP(ADDRESS +5)
7100 HIGH=INP(ADDRESS +6)

```


Program "ASHRAE14.BAS" page 7 of 8

```

7110 T=256 * HIGH + LOW
7120 IF T> 32767 THEN T=T-65536!
7130 VOLTAGE=T*K5*1000          'VOLTAGE IS IN MILLIVOLTS
7140 B(Y)=VOLTAGE
7150 NEXT Y
7160 RETURN                    'read again after control
7170 STOP
7999 '*****
8000 FOR U1=1 TO M1            ' U1,M1    initialization loop to send stat
8010 B$=C$(U1)                 ' B$,C$,U1  change variable for handshake
8020 C=0                        ' C        array counter
8030 J=LEN(B$)                 ' J,B$    find number of commands
8040 FOR K=1 TO J              ' K,J     loop for each command
8050 C=C+1                     ' C        increment array counter
8060 S=ASC(MID$(B$,K,1))       ' S,B$,K  get ASCII value of comm char
8070 A(C)=S                    ' A(*),C,S  put ASCII value in array
8080 NEXT K                    ' K        end of command loop
8090 IF A(1)=81 GOTO 8120      ' A(*)    test for Q command
8100 C=C+1                     ' C        on no Q increment counter
8110 A(C)=13                   ' A(*),C  on no Q add carriage return
8120 OUT SR,190                ' SR      make sure I/O request is high
8130 FOR K=1 TO C              ' K,C     this loop does the I/O handshake
8140 S=INP(SR)                 ' S,SR    test BSY/RDY line to see if high
8150 IF S<128 GOTO 8140        ' S        if low, keep testing
8160 OUT DAR,A(K)              ' DAR,A(*) put data on controller bus
8170 S=INP(DAR)                ' S,DAR   read data back in from bus
8180 IF S>>A(K) GOTO 8260      ' S,A(*)  error if data in <> data out
8190 OUT SR,62                 ' SR      drive I/O request low
8200 S=INP(SR)                 ' S,SR    test BSY/RDY line to see if low
8210 IF S>=128 GOTO 8200       ' S        if high keep testing
8220 OUT SR,190                ' SR      drive I/O request high
8230 NEXT K                    ' K        next command character
8240 NEXT U1
8250 RETURN
8260 PRINT "DATA ERROR: PROGRAM ABORTED" '      data not received on data bus
8270 STOP
9000 '*****
9010 '                          INITIALIZE TIMER COUNTER 1
9020 '*****
9050 OUT 1823,&H90 'INITIALIZE PORT A - INPUT  B - OUTPUT  C - OUTPUT
9060 'INITIALIZE THE COUNTERS
9070 ADDR=1808
9080 OUT ADDR+9,23 'SET DATA POINTER TO MASTER MODE
9090 OUT ADDR+8,0  'SET MASTER MODE REGISTER TO BCD DIVISION
9100 OUT ADDR+8,208
9110 OUT ADDR +9,1 'POINT TO CMR1
9120 OUT ADDR+8,&H21 'SETUP A 1 HZ CLOCK
9130 OUT ADDR+8,&HF 'HI BYTE
9140 OUT ADDR+9,9  'POINT TO LOAD REGISTER 1
9150 OUT ADDR+8,TM 'LOAD THE REGISTER WITH 1000

```

```

Program "ASHRAE14.BAS" page 7 of 8
9160 OUT ADDR+8,0
9170 'ALL OTHER TIMER COUNTER INITIALIZATION ROUTINES GO HERE
9180 OUT ADDR+9,97 'LOAD AND ARM COUNTER 1
9190 OUT ADDR+9,3 'READ HOLD REGISTER UNTIL BECOMES A 0
9200 RETURN
9210 STOP
9280 '*****
9290 '          Stopping routine on cntrl break
9295 '*****
9300 CLOSE #1 :CLS          'closes the speed disk d as an output file
9310 BEEP
9320 BEEP
9330 PRINT"data stored in drive c with the name",P$
9340 PRINT"to plot the data use program 'plotter'"
9350 END

```


ENTER ONE OF THE NUMBERS BELOW

- 1 CONTROL VALVE 1.....CALIBRATION HEATER
- 2 CONTROL VALVE 2.....3 WAY VALVE
- 3 CONTROL VALVE 3.....CONTROL HEATER (ADJUST TO .7 GPM)
- 4 GO ON TO THE CONTROL SEGMENT
- 5 ABORT
- ?

VALVE 1.....CALIBRATION HEATER VALVE 1 PULSE= 0 VALVE 3 PULSE= 0

TO CONTROL A VALVE SELECT A SHIFTED FUNCTION KEY

1OPEN 2PULSO 3CLOSE 4PULSC 5RESTR 6ABORT 7 8 9 0

TO INITIALIZE THE STEPPING MOTORS FIRST BE SURE THAT THE POWER TO THE
 VARIAC AND RHEOSTAT HAS BEEN REMOVED
 NOW PLEASE POSITION THE VARIAC AND RHEOSTAT AT TOP END
 NOW PLEASE PLUG IN THE POWER FOR THE CONTROL HEATER
 PRESS RETURN AFTER YOU HAVE DONE THIS?

input file name for data storage
 ?test3.dat

| | | |
|----|---|---------------|
| 1 | 0 | -2.636719E-02 |
| 2 | 0 | -.03125 |
| 3 | 0 | -4.492188E-02 |
| 4 | 0 | -4.101563E-02 |
| 5 | 0 | -3.027344E-02 |
| 6 | 0 | -4.199219E-02 |
| 7 | 0 | -4.003906E-02 |
| 8 | 0 | -.0390625 |
| 9 | 0 | -4.003906E-02 |
| 10 | 0 | -.0390625 |
| 11 | 0 | -4.394532E-02 |
| 12 | 0 | -4.003906E-02 |
| 13 | 0 | -.0390625 |
| 14 | 0 | -2.832031E-02 |
| 15 | 0 | -.03125 |

C
 ^Break in 7120#
 OK#

Program "PLOTV1.BAS", page 1 of 3

Program Developed using
IBM XT Computer System

```

10 CLS
20 PRINT"PROGRAM PLOTV1.BAS"
30 PRINT
40 PRINT" Program to output voltages from the DACs on the LAB MASTER board"
50 PRINT" to an x - y plotter."
60 PRINT" Data from the specified file will be plotted with respect to time"
70 PRINT" (x-axis). "
80 PRINT " In order for this program to run properly, DAC0 AND DAC1 must be
90 PRINT " hardware jumpered on the lab master board for 0 TO 10 volts"
100 INPUT" ARE THE DACS SET AT 0 TO 10 VOLTS?",T$
110 IF T$="N" THEN STOP
120 ADDRESS = 1808 'Starting address of LAB MASTER board
130 CLS
140 PRINT"1      4095 seconds"
150 PRINT"2      2047 seconds"
160 PRINT"3      1023 seconds"
170 PRINT:PRINT:
180 INPUT"Enter the amount of time full scale on the x axis ",T2
190 IF T2=1 THEN T3=4095:GOTO 230
200 IF T2=2 THEN T3=2047:GOTO 230
210 IF T2=3 THEN T3=1023:GOTO 230
220 PRINT"Enter either a 1,2 or 3 please":CLS:GOTO 140
230 PRINT:CLS:PRINT:PRINT "      X - Y PLOTTER ROUTINE":PRINT
240 PRINT " DAC 0 is the X axis (time)"
250 PRINT " DAC 1 is the y axis (data)"
260 RANGE0=1
270 RANGE1=1
280 INPUT "Do you want to draw a frame ";I$
290 IF I$ = "N" THEN GOTO 630
300 DECIMAL = -2048
310 NUMBER = 0: GOSUB 1120 'MOVE PEN TO 0,0
320 NUMBER = 1: GOSUB 1120
330 PRINT DECIMAL
340 FOR I = 1 TO 4095
350 DECIMAL = DECIMAL + 1 'MOVE PEN UP
360 GOSUB 1120
370 V$ = INKEY$
380 IF V$ = CHR$(3) THEN STOP
390 NEXT I
400 PRINT NUMBER,DECIMAL
410 DECIMAL = -2047
420 NUMBER = 0
430 FOR I = 1 TO T3-1
440 DECIMAL = DECIMAL + 1 'MOVE PEN TO RIGHT
450 GOSUB 1120
460 NEXT I
470 PRINT NUMBER,DECIMAL
480 DECIMAL = 2047
490 NUMBER = 1

```

Program "PLOTV1.BAS", page 2 of 3

```

500 FOR I = 1 TO 4095
510 DECIMAL = DECIMAL - 1           'MOVE PEN DOWN
520 GOSUB 1120
530 NEXT I
540 PRINT NUMBER,DECIMAL
550 DECIMAL = -2048+T3
560 NUMBER = 0
570 FOR I=1 TO T3
580 DECIMAL = DECIMAL - 1         'MOVE PEN TO LEFT
590 GOSUB 1120
600 NEXT I
610 PRINT NUMBER,DECIMAL
620 CLS:GOTO 40
630 INPUT "Input file name for data retrieval ",FILE$
640 IF LEN (FILE$) <= 11 THEN GOTO 670
650 PRINT "File name length must be less than 11 characters in length."
660 GOTO 630
670 OPEN FILE$ FOR INPUT AS #1
680 INPUT"ENTER THE STARTING DATA POSITION IN THE SEQUENTIAL FILE ",DF
690 INPUT "MAXIMUM POSITIVE SCALE 100,10,5,OR 2.5 ",MULT
700 IF MULT=100 THEN K1=20 : GOTO 750
710 IF MULT=10 THEN K1=2 :GOTO 750
720 IF MULT=5 THEN K1=1 :GOTO 750
730 IF MULT=2.5 THEN K1=.5 :GOTO 750
740 GOTO 690
750 GOSUB 1260
760 PRINT TIME$
770 FOR I = 1 TO T3
780 INPUT #1,Y
790 Y=(Y/K1+5)           'convert (-10 to +10 ) to (0 to 10) for scaling
800 NUMBER = 1           'point to DAC 1 (y axis)
810 VOLTAGE = Y
820 GOSUB 900
830 NUMBER = 0
840 DECIMAL = I + -2049
850 GOSUB 1120
860 NEXT I
870 PRINT TIME$
880 CLOSE #1 :BEEP: BEEP : BEEP :END
890 STOP
900 REM      This subroutine outputs the selected voltage to the selected DAC
910 REM      Where:
920 REM          NUMBER - 0 for DAC 0
930 REM                  - 1 for DAC 1
940 REM          VOLTAGE - the desired voltage
950 REM          RANGEn - 1 for 0 to 10 volts
960 REM                  - 2 for -10 to 10 volts
970 REM                  - 3 for 0 to 5 volts
980 REM                  - 4 for -5 to 5 volts

```

Program "PLOTV1.BAS", page 3 of 3

```

990 REM                      RANGEn - 5 for -2.5 to 2.5 volts
1000 REM                      n = 0 or 1 for specified DAC
1010 REM                      ADDRESS - is the starting address of the LAB MASTER board
1020 REM
1030 IF NUMBER = 0 THEN ON RANGE0 GOTO 1050,1060,1070,1080,1090
1040 IF NUMBER = 1 THEN ON RANGE1 GOTO 1050,1060,1070,1080,1090
1050 DECIMAL = 409.5 * VOLTAGE - 2048 :GOTO 1100
1060 DECIMAL = 204.7 * VOLTAGE :GOTO 1100
1070 DECIMAL = 819 * VOLTAGE - 2048 :GOTO 1100
1080 DECIMAL = 409.4 * VOLTAGE :GOTO 1100
1090 DECIMAL = 818.8 * VOLTAGE :GOTO 1100
1100 IF DECIMAL < -2048 THEN DECIMAL = -2048
1110 IF DECIMAL > 2047 THEN DECIMAL = 2047
1120 REM Convert to twos complement
1130 DECIMAL = INT(DECIMAL)
1140 'IF NUMBER = 0 THEN PRINT DECIMAL;" ";
1150 'IF NUMBER = 1 THEN PRINT DECIMAL
1160 V$ = INKEY$
1170 IF V$ = CHR$(3) THEN STOP
1180 HIGH = INT(DECIMAL/256)
1190 LOW =DECIMAL - 256 * HIGH
1200 IF HIGH < 0 THEN HIGH=16+HIGH
1210 REM Output the data to the DAC
1220 IF NUMBER = 0 THEN OUT ADDRESS + 1,HIGH : OUT ADDRESS,LOW 'out to DAC 0
1230 IF NUMBER = 1 THEN OUT ADDRESS + 3,HIGH : OUT ADDRESS+2,LOW 'out to DAC 1
1240 RETURN
1250 STOP
1260 FOR K=1 TO DF-1 ' subroutine to just read the first pieces of data and
1270 INPUT #1,Y1 ' do nothing with the data read.
1280 NEXT K ' the routine lets the data pointer point to the proper
1290 RETURN ' data position...
1300 STOP

```

Program "MEAN.BAS", page 1 of 1 Program Developed using IBM XT
Computer System

```

10 ' The purpose of this basic program is to read data which is stored
20 ' sequentially in a file and to determine the mean and standard
30 ' deviation for 3600 samples.
40 ' The program allows the user to specify the first data point which
50 ' is to be used in the calculations. Note that the position of the data
60 ' point in the sequential file must be specified, not the data point itself
70 ' To obtain the starting position one must use wordstar or a similar text
80 ' editor and count the data's position within the file.
90 ' Note that data stored in a sequential file is in an ascii format and data
100 ' stored in a random file is in a binary format. Sequential take up more
110 ' disk space but allows the user to readily determine the files contents
120 ' Through the use of a text editor.
130 PRINT"PROGRAM MEAN.BAS"
140 PRINT"THIS PROGRAM FINDS THE MEAN AND STANDARD DEVIATION FROM A SEQUENTIAL"
150 PRINT"FILE. THE NUMBER OF SAMPLES TAKEN IS 3600"
160 PRINT:PRINT
170 INPUT"INPUT FILE NAME FOR DATA RETRIEVAL ",FILE$
190 PRINT:PRINT
200 INPUT"ENTER THE STARTING DATA POSITION OF THE SEQUENTIAL FILE ",D
210 OPEN FILE$ FOR INPUT AS #1
211 SUM=0
212 DATA1=0
213 MEAN=0
214 DATA2=0
215 SUM2=0
220 GOSUB 500
230 FOR J=1 TO 3600
240 INPUT #1,DATA1
250 SUM = SUM + DATA1
260 NEXT J
270 MEAN=SUM/3600
280 CLOSE #1
290 OPEN FILE$ FOR INPUT AS #1
300 GOSUB 500
310 FOR K=1 TO 3600
320 INPUT #1, DATA2
330 SUM2=SUM2 + (DATA2-MEAN)^2
340 NEXT K
350 SD=SQR(SUM2/3599)
360 PRINT"FOR THE FILE",FILE$
370 PRINT"STARTING AT POSITION",D
380 PRINT:PRINT
390 PRINT"THE MEAN= ",MEAN
400 PRINT"STANDARD DEVIATION= ",SD
410 CLOSE #1
420 END
500 FOR I=1 TO D-1
510 INPUT #1,Y      'DO NOTHING
520 NEXT I
530 RETURN

```

PROGRAM MEAN.BAS

THIS PROGRAM FINDS THE MEAN AND STANDARD DEVIATION FROM A SEQUENTIAL
FILE. THE NUMBER OF SAMPLES TAKEN IS 3600

INPUT FILE NAME FOR DATA RETRIEVAL test5.dat

ENTER THE STARTING DATA POSITION OF THE SEQUENTIAL FILE 2200
FOR THE FILE test5.dat
STARTING AT POSITION 2200

THE MEAN= 1.227186E-02
STANDARD DEVIATION= .5469745

PROGRAM MEAN.BAS

THIS PROGRAM FINDS THE MEAN AND STANDARD DEVIATION FROM A SEQUENTIAL
FILE. THE NUMBER OF SAMPLES TAKEN IS 3600

INPUT FILE NAME FOR DATA RETRIEVAL test5.dat

ENTER THE STARTING DATA POSITION OF THE SEQUENTIAL FILE 5800
FOR THE FILE test5.dat
STARTING AT POSITION 5800

THE MEAN= 1.209364E-02
STANDARD DEVIATION= .3349528

D>

VITA

William Emanuel Kramer

Candidate for the Degree of

MASTER OF SCIENCE

Thesis: A Control Subsystem for a Standard Device For Calibrating
Calorimeter Rooms

Major Field: Mechanical Engineering

Biographical:

Personal Data: Born in Minot, North Dakota, January 4, 1959, the son of
Robert H. and Cheryl A. Kramer.

Education: Graduated from Smoky Hill High School, Denver, Colorado in
May of 1977. Received an Associates of Arts degree from Hutchinson
Community College, Hutchinson, Kansas in May of 1980. Received a
Bachelor of Science degree in Mechanical Engineering from Kansas
State University in December, 1982. In July, 1984 the requirements
for a Master of Science in Mechanical Engineering were completed at
Kansas State University.

A CONTROL SYSTEM FOR A STANDARD
DEVICE FOR CALIBRATING CALORIMETER ROOMS

by

WILLIAM EMANUEL KRAMER
B.S., Kansas State University, 1982

AN ABSTRACT OF A THESIS

submitted in partial fulfillment of
the requirements for the degree
MASTER OF SCIENCE

Department of Mechanical Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1984

A CONTROL SYSTEM FOR A STANDARD DEVICE
FOR CALIBRATING CALORIMETER ROOMS

ABSTRACT

A control system is developed to control the power to an electric heater in order to maintain the average temperature difference between two liquid flow streams to be within ± 0.006 degrees Fahrenheit. The control system is to be used in a standard device for calibrating calorimeter rooms. The calibration device will be used to determine the cooling capacity of calorimeter rooms to within ± 0.5 percent.